SLOPE STABILITY ANALYSIS OF OPEN CAST MANGANESE ORE MINE-DONGRI BUZURG MOIL

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

B.Tech & M.Tech Dual Degree

IN

MINING ENGINEERING

By

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DEPARTMENT OF MINING ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
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CERTIFICATE

This is certify that the thesis entitled "**SLOPE STABILITY ANALYSIS OF OPEN CAST MANGANESE ORE MINE- DONGRI BUZURG MOIL**" submitted by Shri Laxman Pal, Roll No.710MN1143 in partial fulfilment of the requirements for the award of B.Tech & M.Tech Dual Degree in Mining Engineering at the National Institute Of Technology, Rourkela is authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Date: 27-MAY-2015

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An assemblage of this nature would not be possible without reference to and inspiration from the works of others whose details are mentioned in reference section. I acknowledge my indebtedness to all of them. My sincere thanks to all my friends and research scholars in the Dept. who have patiently extended all sorts of helps for accomplishing this assignment.

Finally, I humbly bow my head with utmost gratitude before the God Almighty who always guided me all the way and without whom nothing could have been possible.

Date: 27-MAY-2015

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CONTENT

ABSTRACT

Slope stability analysis are one of the most leading need in surface mining operations to predict the unexpected movement of ground causes, which has a potential to endanger lives, demolish equipment, or destroy property. Therefore, slope stability analysis in MOIL-Dongri Buzurg was done by conducting joint survey of mine and analysis of primary structure such as bedding has been obliterated in the schistose footwall and hang wall due to prominent schistocity. Dips are southerly and vary from 45^o to 80^o. Kinematic analysis of the joints by using DIPS software shows potential wedge failure in footwall side with 33.33% which shows sufficient potential failure in footwall side. And in hangwall side, it was 16.67% which has quite lower chances of failure. For determining physico-mechanical properties of the rocks, samples were collected and tested in laboratory. Strength properties of rock mass were determined by using RMR which was found to be 42 and comes under the category of fair rock type. Uniaxial compressive strength of Quartz muscovite schist, Tirodi biotitic gneiss and Quartz mica schist were determined 55, 69.86 and 61.12 MPa respectively. Similarly, shear strength properties of rock were obtained by using Triaxial testing. Cohesion values determined by using Triaxial tests values for Tirodi biotitic gneiss, Granitic gneiss and Quartz mica schist were 2.13, 2.4 & 2.64 MPa and friction angles are 39.6^0, 41.9^0, 43.9^0 respectively directly by using RocData software. From parametric studies with above physico-mechanical properties, bench angle is determined to be 65^o with bench height 10 m for the geomining conditions of the MOIL-Dongri Buzurg mine.

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CHAPTER-1

INTRODUCTION

1. INTRODUCTION

Slope stability analysis of open cast mine is a routine event and required for operating safely. Monitoring slope stability enables warning against any type of failure before it actually happens and that could provide sufficient time to evacuate the area. Assessment of the stability of slopes in open pit mines at different stages of mining is important for the safe and economic mining operations. Slopes are generally designed based on the geotechnical data and physico-mechanical properties of rock/soil. From geotechnical data, the rock mass quality is assessed, and from this, the rock mass properties are estimated. Using the rock mass properties stability of the slopes is evaluated from empirical, analytical and numerical techniques.

In homogenous, isotropic ground conditions, the factor of safety can be determined for predefined failure modes using limit equilibrium method (Hoek. and Bray, 1981; Hoek, 1986; Piteau & Martin, 1981; Zanbak, 1983). Similarly, using analytical solution given by Xiao Yuan & Wang Sijing (1990), flexural breaking of rock mass can be determined. Design charts can be developed using limit equilibrium method. Some design charts are available for plane, wedge, circular modes of failure (Hoek & Bray, 1981), and for toppling failure (Choquet &Tanon, 1985; Zanbak, 1983). The field engineer can use them if the basic geotechnical properties are known. These charts are useful to analyze only simple types of predetermined failures, but not for determining the slope angle which depends on the rock mass stability.

Project site, MOIL-Dongri Buzurg mine is fully mechanized which allows for higher recovery rates, permitting an increasing percentage of manganese ore to be recovered by way of crushing, screening and sorting of waste, thus improving productivity and higher sales. Under this project, the slope stability parameters in ***Dongri Buzurg*** open pit mine with site specific geomining conditions were studied. Detailed geotechnical studies were carried out in the field, and based on this, the existing suitable rock mass classification system was applied along with numerical modeling. Based on these studies, and further studies on modeling by using FLAC and OASYS and rock testing were done to simulate the mining condition.

1.1 Objective

The basic objective of the project is to analyses the stability of slope for benches of footwall and hangwall at Dongri Buzurg mine-MOIL.

1.2 Methodology Adopted

To fulfill the objectives of the project, detailed literature survey was carried out to identify the methods available for characterization of the rock mass in slopes. A field visits were conducted for collection of relevant data and discussions with the Mine officials. A number of rock samples were tested to determine physico-mechanical properties. The tests for determination of the above Physico-mechanical properties were conducted in laboratory. Following are some of the work elements for conducting the above study:

- Collection of relevant data
- Samples of rocks collected from MOIL and being tested in laboratory. Some of the collected samples were not of adequate size for testing.
- Based on the above data from the mine, analysis is being carried out using empirical and numerical techniques to assess slope stability.

The rock samples collected from the mine were tested to determine the physico-mechanical properties. The geotechnical data collected in the mines include : a) joint dip amount / dip direction; b) joint spacing; c) condition of the discontinuities; and d) geometry of the pit.

Ground water was not a major factor affecting the stability at the mines studies. The other instruments were also not used, as tension cracks was not a major phenomenon in the selected mines. Numerical modeling was carried out to determine the factor of safety for different slope geometries and likely failure surfaces. Based on these analyses, the bench parameters were analyzed.

CHAPTER-2

LITERATURE REVIEW

2. LITERATURE REVIEW

Different sets of paper were studied for analyzing the geomining condition and slope stability Techniques used in world mining. Geological conditions of various mineral deposits were done by many investigators including RMR, SMR etc. and numerical modeling. Rock mass properties were considered by few investigators in numerical modeling for slope stability studies with continuum media in many studies while very few studies were done using and discontinum models. Extensive lab testing and numerical modeling was not available for many reported studies. Recommendation for further studies with meticulous lab tests, rock mass properties, discontinum models, field instrumentation and calibration of the models was proposed by many investigators.

Table 2.1: Work done by others on slope stability and geological study on manganese ore deposits of central India

SL No.	AUTHOR	TITLE	DESCRIPTION
1.	Rasheed A. Adebimpe et. al. [3]	Slope stability analysis of Itakpe, Iron ore mine, Itakpe, Nigeria	Rock mass characterization is must to design surface & underground mines. Rock samples of iron ore, granites& gneiss were collected and tested in laboratory to obtained UCS, tensile, Unit weight, friction angle, cohesion, bulk density and other physic-mechanical properties. And other parameters values are obtained from rock mass characterization equation and RMR values by using Beniawaski. UCS, tensile strength, porosity

			and bulk modulus of iron ore are 142.90 KN/m^2, 6.23 KN/m^2, 0.018 and 3.79 $tons/m^3$ respectively. RMR values of the mine are classified as good quality rock. RMR values are one of the most useful data to design open pit & slope design.
2.	Talat Jawed et. al. [2]	Mineragraphic study of manganese ore deposits of Kandri, Mansar, Beldongri and Satak mines, Nagpur district (Maharashtra) central India	This paper discuss about mineralogy, texture & paragenesis of the manganese ore of Kandri, Mansar, Satak & Beldongri. These manganese ore are formed by multiple process like metamorphism & supergene enrichment. Presence of lamellar twining indicate shear pressure.
3.	S. Mohanty et. al. [1]	Stratigraphic position of the Tirodi Gneiss in the Precambrian terran of central India: Evidence from the Mansar area, Nagpur, Maharashtra	This paper presents the relation between different Gneiss & schist belt which has not been solved, though Tirodi gneiss is considered a basement of Sausar Group. Sausar Group mainly mapped in Manasar area of Nagpur district, Maharashtra. Presence of gneiss pebbles in the conglomerates indicate that the gneiss unit was source of pebbles & act as basement of Sausar group.

4.	Supriya Roy et. al. [4]	Mineralogy and Gneiss of the Gondites associated with metamorphic manganese ore bodies of Madhya Pradesh and Maharashtra, India	This paper discuss about manganese ore deposits of Madhya Pradesh & Maharashtra. Their mineralogy & gneiss of gondites are mainly metamorphosed manganiferous rock associated with above manganese deposits. These gondites are made up of garnet, and quartz mainly. Tirodi is predominantly made up of cummingotonite molecules with heavy presence of soda tremolite.
5.	A.R Bye et.al. [5]	Stability assessment and slope design at Sandsloot open pit, South Africa	This paper contains slope stability analysis of world largest open pit mine platinum mine, named as Sandsloot, situated in South Africa. There are three recognized joint set which affect slope stability, notably in terms of wedge and planar failure. Geological and geotechnical data have been obtained by mapping, scan line survey, exploration drills and from laboratory testing. These data used to analyses different potential of rock mass failure. And used all the above obtained data to design parameters to improved slope stability. This analysis resulted by increase in

			the ultimate angle of the wall by 7^0 with improved safety and substantial savings.
6.	HAO Fengshan et al [6]	Application study of FLAC in analysis of slope stability	This paper offering proposal for slope control & slope stability analysis. FLAC software is mainly used for analysis of geotechnical engineering. FLAC is introduced with theoretical basis and specific calculation steps are being involved. Different problem related to FLAC numerical analysis, numerical calculation are discussed combine with loess landslide.
7.	Zhiqiang Yang et al [7]	Stability analysis & design of open pit mine slope in china: A review	This paper discuss about issues of design & stability analysis of open cast mine slope. The key technology used to analyses slope stability of mine are as follows: 1. Limit equilibrium 2. Numerical simulation 3. Reliability analysis 4. "3S" technology 5. Equivalent pattern recognition technology.

CHAPTER-3

GEOMINING CONDITION

3. DETAILS OF ORE BODY

The manganese ore horizon occurs in the lower part of the sequence of meta-sedimentary rocks of Sausar Group of Pre-Cambrian age. The Sausar group extends broadly in ENE-WSW direction from Balaghat district, M.P. in the east, through Bhandara district to Nagpur district, in the west, comprising within it the famous manganese belt of Central India. This belt stretches over a length of 200 km and is about 25 km wide in the Central part. In the central part, within an area of about 1,000 sq.km. bounded by latitude 21º21' to 21º36' and longitude 79º30' to 80º00' included in topo sheet nos. 55 O/10,11,14 and 15, the manganese belt comprises of number of Mn ore deposits, of which Dongri Buzurg is one of the largest deposits. Rocks representing the lower part of the Sausar Group sequence viz. Tirodi gneisses, Sitasaongi and Munsar formation occur in and around Dongri Buzurg Mine. Lohangi formation is absent from the area. The Manganese horizon occurs at the stratigraphic contact of the Sitasaongi and Munsar Formations. Manganese ore is associated with Gondite, a regionally metamorphosed manganiferous and non-calcareous rock, characterized by spessartite (a manganese almandine garnet) and quarts with or without manganese silicates showing essentially bedded characteristics of enclosed pelitic meta sedimentary rocks.

Fig.3.1: Overview of the Dongri Buzurg Mine, MOIL

3.1 Regional Geological Setup

The regional strike of formations is E-W varying to ENE-WSE locally, with moderate to steep southerly dips (45º to 70º). Bedding and foliation are parallel as observed in the well bedded quartzite and manganese ore horizon and the enclosing schist. Structurally, the formations are isoclinally folded, with axial plane tilting towards south at 45º to 70º. Table 3.1 shows the generalized sequence of Sausar group.

Table 3.1: The Generalized sequence of Sausar group

GEOLOGICAL AGE	STRATIGRAPHICAL NOMENCLATURE	ROCK TYPES
Recent and Sub-recent Tertiary	---------	Soil and Laterite
	Magmatic intrusive	Pegmatite & vein quartz. Medium to coarse grained leucocratic granites
	Ortho genesis	Ortho-gneisses, biotitic muscovite gneisses
	Bichua	Dolomitic marble, Calc silicate rock
	Junewani	Quartz-biotite granulite and biotite schist, biotite gneisses
	Chorbaoli	Quartzites-micaceous quartzite & quartz muscovite schist
	Munsar	Muscovite schist, garnetiferousschist, sericiteschist
MANGANESE ORE HORIZON		
	Lohangi/Sitasaongi	Calciticmarble / quartzite and mica schist,quartzschistFeldspathic mica schist.
	Tirodi Gneisses	Streaky Biotite gneiss, banded and foliated amphibolites.

Fig.3.2: Footwall of the Dongri Buzurg Mine, MOIL

Dongri Buzurg ridge represents an inverted northern limb of a regional anticline, pitching towards east and closing about 8 km east of the area near Chikla mines of MOIL. As a consequence of this inversion, the older formations like Tirodi gneisses and Sitasaongi formation constitute the hanging wall of the manganese ore horizon and younger Munsar schist from the footwall.

3.2 Geology of Dongri Buzurg Mine

The geology of the area is described below.

3.2.1 Tirodi formation

Tirodi Gneisses comprise of streaky, banded, augen gneisses and granitoid gneisses with small lenticular bodies of granitic rock. These rocks occupy southern gentle slope of the Dongri Buzurg hill. These exposures are now been covered by dumps. Some prominent exposures are however seen on high ground south east of mine office. The gneisses exposed in south eastern corner of the area are mostly well foliated, streaky and banded with alternating dark bands rich in biotite and light band comprising of quartz and Felspathic material. The gneisses intersected in bore holes are of crudely foliated granitoid type in addition to the usual streaky, banded and foliated variety.

3.2.2 Sitasaongi formation

Quartz-mica Schist and quartzite exposed on the southern slope of the Dongri Buzurg ridge and apparently underlying the (Tirodi) gneisses mostly with a gradational contact, belong to the Sitasaongi formation. These rocks are mostly medium to fine grained.

There is considerable variation in the thickness of Sitasaongi formation. At both the ends the Tirodi gneisses have grown at the expense of Sitasaongi formation. In the central thick portion the quartz-mica-schist and quartzites are seen to be felspathised to a considerable extent. The feldspars have been kaolinised and at places pockets of clay have been observed particularly near the contact of Sitasaongi formation and manganese ore horizon. This may be due to circulation of water along this contact. The bedding in quartzite and foliation in quartz-mica-schist, have not been obliterated due to felspathisation and trend E-W in general, with minor swing to ENE-WSW towards the western end with moderate to steep southerly dips (48 to 68º). Rolling dips are observed towards the top of the hill.

3.2.3 Munsar formation

The manganese ore horizon is conformably underlain by coarse highly puckered mica schist belonging to Munsar formation. The mica schist is coarse, pale green to pale pink, soft and fissile with crystals of garnet and magnetite. These are exposed all along the crest of the Dongri Buzurg hill forming the footwall of the ore body.

There is very little variation in the rock type of Munsar formation. Near the contact of manganese ore horizon and the underlying Munsar mica schist manganese nodules are found. A thin sheet like band of manganese ore was also found interlayered with the mica schist. This band is fairly hard and therefore stands out on foot wall benches, which were mechanically cut in the past. Mica schist is traversed by minor quartz veins and pegmatite mostly along the foliation.

CHAPTER 4

JOINT SURVEY

4.0 JOINT SURVEY

Joint survey was conducted during field visit at MOIL-Dongri Buzurg. Table 4.1 and table 4.2 gives no. of joints per meter and strike value and DIP of slopes in footwall and hangwall of mine respectively. Joint survey was conducted for five benches of footwall side and four benches of hangwall side are as shown in table 4.1 & 4.2. The joint survey was conducted between 350-310 MRL'S in footwall side and hang wall side 329-291m MRL. The total no of benches exist in hangwall (347-276) m MRL and foot wall (391-296) m MRL side are 8.The following Fig.4.1 shows the mine plan of Dongri Buzurg mine with different benches.

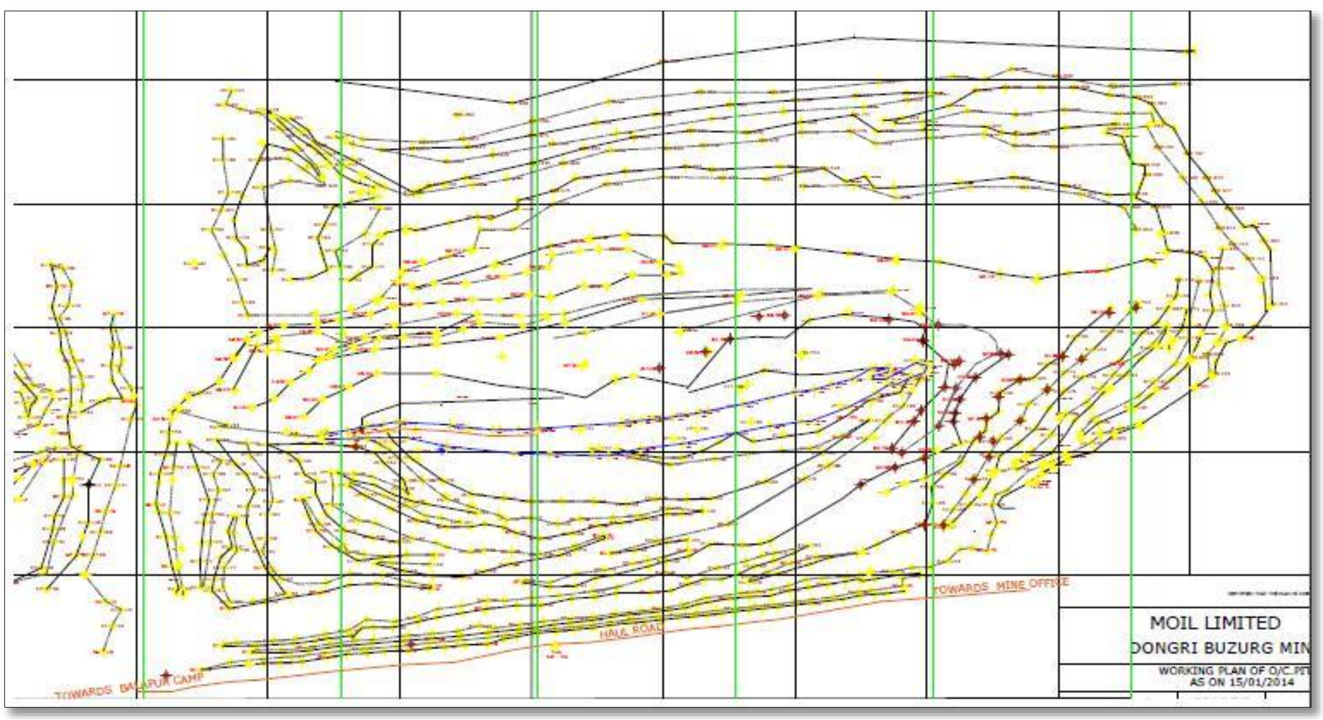


Fig.4.1: Plan of Dongri Buzurg mine, MOIL

4.1 Joint Survey Details

Table 4.1 containing the data with Bench & MRL, strike, Dip, Joint/m and distances, which were obtained during joint survey at Dongri Buzurg mine for footwall benches.

Table 4.1: Details of Joint survey conducted at footwall of Dongri Buzurg MOIL

BENCH&MRL(FW)	STRIKE	DIP	JOINTS/m	DISTANCE
3f-350m	26^0	$N26^0E$	2	57
3f-350m	68^0	$N5^0$ E	3	30&55
3f-350m	81^0	25^0	1	
3f-350m	71^0	10^0	1	
3f-350m	55^0	22^0	0	
3f-350m	65^0	5^0	1	
3f-350m	65^0	16^0	1	
3f-350m	71^0	9^0	1	
3f-350m	60^0	16^0	1	
3f-350m	62^0	11^0	1	
3f-350m	40^0	12^0	2(1V-1H)	50
3f-350m	62^0	9^0	2	60
2f-360m	50^0	15^0	4	
2f-360m	85^0	25^0	3	
2f-360m	74^0	14^0	2	
2f-360m	95^0	10^0	3	
2f-360m	55^0	4^0	4	
2f-360m	60^0	30^0	3	
2f-360m	35^0	6^0	4	
2f-360m	55^0	18^0	3	
2f-360m	55^0	10^0	1	40
2f-360m	65^0	6^0	4	
2f-360m	75^0	5^0	5	
2f-360m	60^0	5^0	2	

2f-360m	60^0	10^0	3	
2f-360m	55^0	5^0	5	
2f-360m	45^0	4^0	2	
2f-360m	70^0	9^0	3	
2f-360m	30^0	5^0	2	
2f-360m	40^0	3^0	6	
2f-360m	30^0	25^0	3	
2f-360m	80^0	10^0	1	30
2f-360m	40^0	11^0	3	
2f-360m	70^0	9^0	3	
2f-360m	40^0	10^0	3	
2f-360m	55^0	5^0	2	
2f-360m	40^0	3^0	1	10
2f-360m	35^0	9^0	3	
2f-360m	55^0	3^0	2	
2f-360m	40^0	9^0	2	
4f-340m	115^0	10^0	1	
4f-340m	110^0	1^0	0	
4f-340m	40^0	3^0	2	
4f-340m	70^0	15^0	4	
4f-340m	65^0	5^0	3	
4f-340m	50^0	15^0	4	
4f-340m	60^0	4^0	4	
4f-340m	65^0	5^0	1	
4f-340m	60^0	6^0	2	
4f-340m	50^0	20^0	3	
5f-330m	65^0	6	0	
5f-330m	70^0	10	2	
5f-330m	95^0	5	1	

5f-330m	45^0	15	Many	
5f-330m	85^0	20	3	
5f-330m	60^0	4	2	
5f-330m	55^0	11	1	
7f-310m(bottom)	72^0	15^0	0	
7f-310m	80^0	5^0	1	
7f-310m	78^0	16^0	1	
7f-310m	70^0	5^0	10	
7f-310m	85^0	5^0	3	
7f-310m	40^0	16^0	1	
7f-310m	65^0	4^0	1	
7f-310m	30^0	20^0	0	

4.2. Some Images of Joint Survey of Footwall Side

Glimpse of the photo which were taken during joint survey of footwall are shown in the figure 4.2(a) to fig. 4.2 (c).

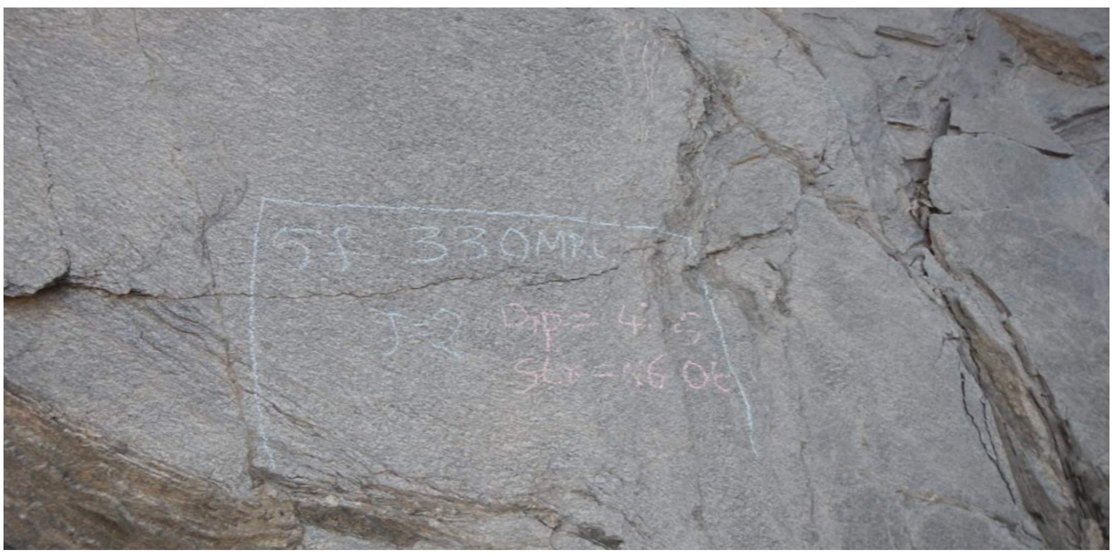


Fig.4.2 (a): Joint survey images: Bench -5, footwall Joints=2, dip=4^0, strike=60^0

Fig.4.2 (b): Joint survey images: Bench-7, footwall Joints=4, dip=12^0, strike=235^0

Fig.4.2 (c): Local failure at 350 MRL at footwall bench.

Table 4.2 contains the data with bench & MRL, strike, Dip and Joints/m and distances, which were obtained during joint survey of hangwall at Dongri Buzurg mine-MOIL.

Table 4.2: Details of Joint survey conducted at hangwall of Dongri Buzurg-MOIL

BENCH&MRL(HW)	**STRIKE**	**DIP**	**JOINTS/m**	**DISTANCE**
7h-291m	290^0N	S11^0W	OB	OB
7h	230^0N	S20^0W	OB	OB
7h	240^0	4^0W	2	40
7h	200^0	11^0	2	40
7h	290^0	35^0	1	40
7h	300^0	25^0	1	20
7h	220^0	12^0	1	60
7h	220^0	14^0	5	
7h	230^0	10^0	1	45
7h	240^0	4^0	3	10&15&25
7h	270^0	8^0	3	
7h	265^0	10^0	2	
7h	245^0	11^0	2	
7h	235^0	12^0	4	
7h	225^0	5^0	5	
7h	270^0	12^0	2	
4h-303m				
4h	295^0	12^0	0	0
4h	275^0	10^0	0	0
4h	250^0	11^0	2	50
4h	320^0	10^0	0	
4h	330^0	5^0	2	40
5h				
5h-318m	220^0	6^0	3	

5h-318m	240^0	15^0	0	
5h	250^0	1^0	1	10
5h	225^0	15^0	2	
5h	263^0	15^0	2	45
5h	270^0	10^0	2	
5h	230^0	20^0	2	
5h	245^0	25^0	2	
3h-329m	260^0	20^0	0	0
3h	290^0	25^0	1	10
3h	275^0	15^0	2	
3h	250^0	10^0	1	
3h	240^0	9^0	2	
3h	272^0	8^0	2	
3h	270^0	10^0	2	

4.3. Some Images of Joint Survey of Hangwall Side

Glimpse of photo's which were taken during joint survey of hangwall are shown in the figure 4.3(a) to fig. 4.3 (c).

Fig.4.3 (a): Joint survey images: bench-7 hangwall Joints=3, dip=4^0, strike=240^0

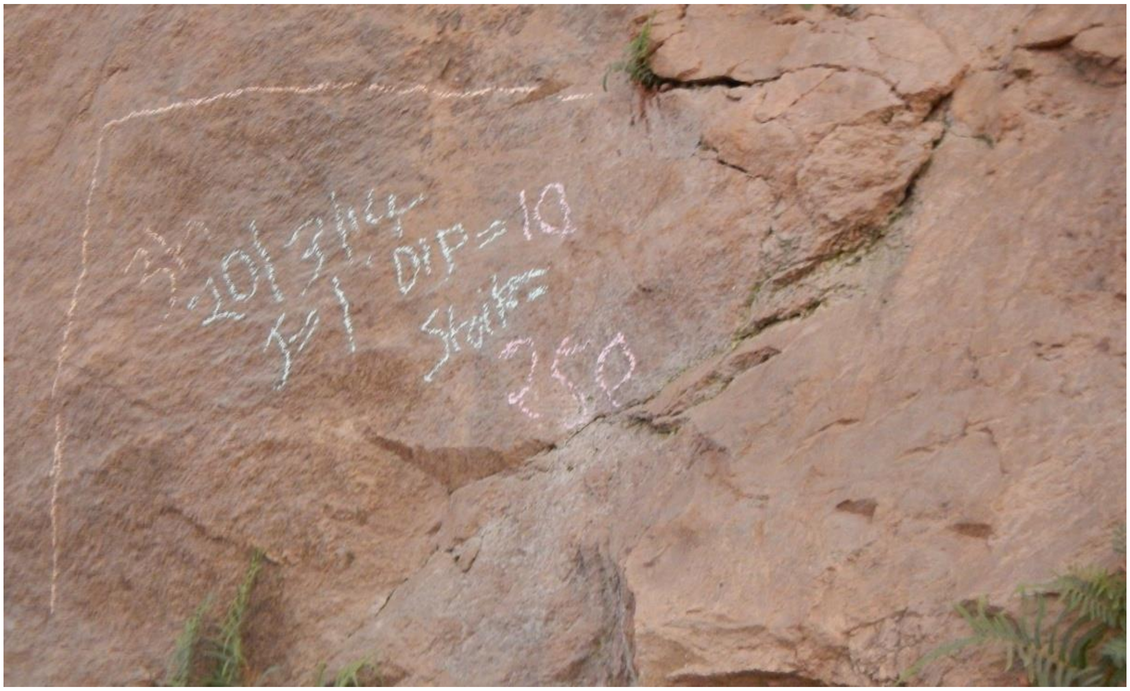


Fig.4.3 (b): Joint survey images: Bench-3 hangwall Joint =1, dip=10^0, strike=250^0

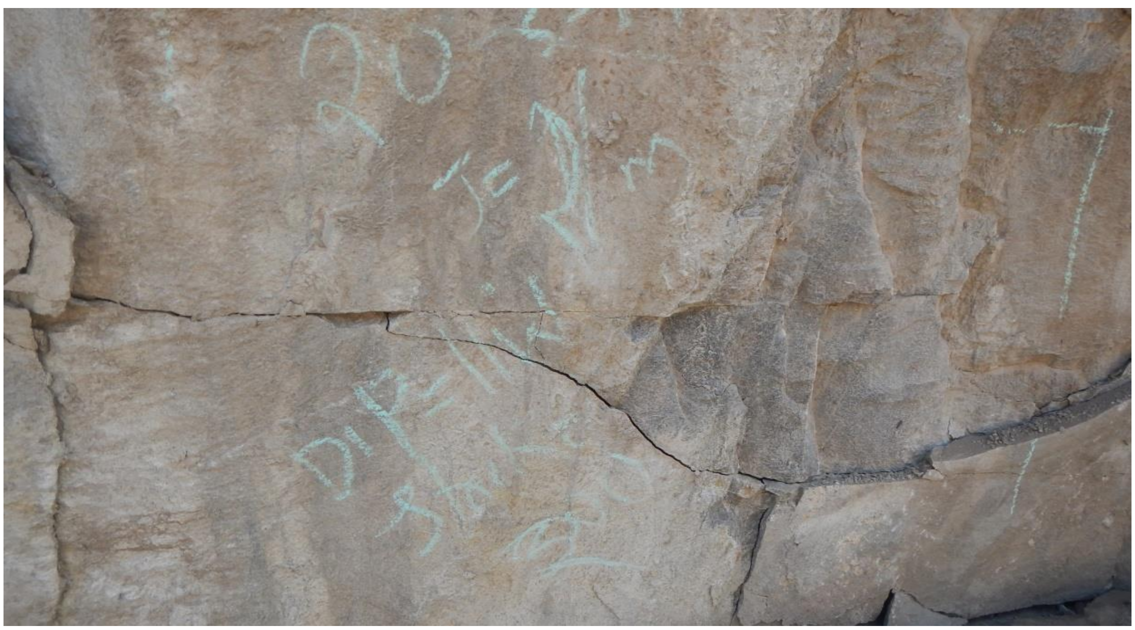


Fig.4.3 (c): Joint survey images: Bench-7 hangwall Joints=2, dip=11^0, strike=200^0

4.4 Joint Survey Analysis for footwall (Strike/ Dip)

A computer software named DIPS was used to assist in this analysis. The hemispherical projections and kinematic analyses are performed for the joint sets identified in MOIL Dongri Buzurg. The kinematic analysis gives a general idea about the type of failures expected, but the slope angles cannot be designed based on these results. But the failures identified by this method can be analyzed in detail by limit equilibrium method. Further, it is not possible to identify circular and non-circular failures using hemispherical projections. Surface exposures were mapped to get the discontinuity data. Within the footwall strata, there are four sets of discontinuities including the schistocity as indicated in Table 4.4.1. They are as follows:

a) Schistocity - its general trend is 50^0 dips due 170^0 (striking roughly E - W).

b) Joint Set no. 1 - these are inclined joints, with roughly E-W strike (dip amount 35^0, and dip direction 345^0). The mean spacing is 40 cm, and the joint surfaces are smooth, planar.

c) Joint Set no. 2 - this set is a westerly dipping set (dip amount 40^0, dip direction 270^0). The joint surfaces were smooth and undulating, and the joint spacing is 1 to 3 m.

d) Joint Set no. 3 - this set has 50^0 dip amount and dip direction is 220^0. The joints in this set have rough, planar surfaces, and the joint spacing is 2 m.

Table 4.4.1: Joint sets of footwall - Dongri-Buzurg Mine [13]

Location	Joint sets from hemispherical projection [joint set no., dip (º) / dip direction (º)]
Footwall	0. 50 / 170 (Schistocity) 1. 35 / 345 2. 40 / 270 3. 50 / 220

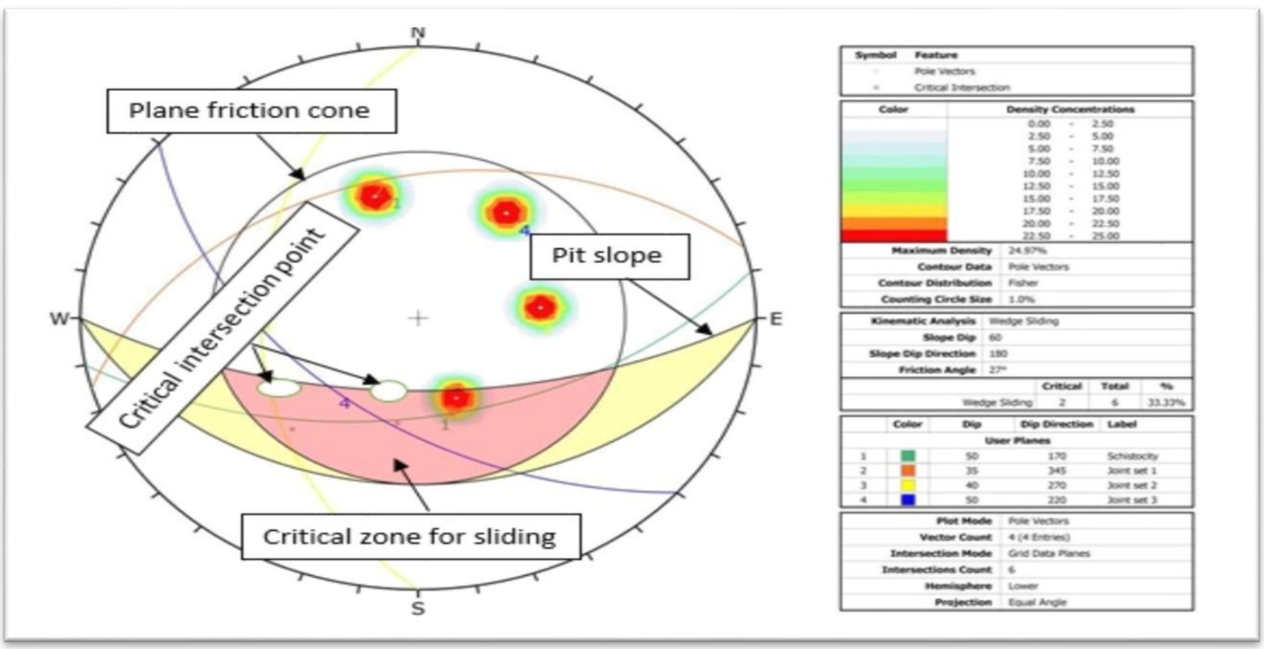


Fig.4.4: Kinematic check for footwall benches – MOIL Dongri Buzurg

Legend from footwall wedge sliding (DIPS)

A summary of wedge sliding result is displayed in legend as indicated in Table 4.4.2

Table 4.4.2: Legend from footwall wedge sliding

Kinematic analysis	Wedge sliding		
Slope dip	60^0		
Slope dip direction	180^0		
Friction angle	27		
	Critical	**Total**	**Percentage**
Wedge sliding	2	6	33.33 %

As it is shown in the above fig. 4.4.1 & legend table 4.4.2, there are four mean set planes intersecting each other and thus form six intersection points. Among all six intersection points there are two intersection points which are lying in the critical wedge sliding zone.

Hence percentage of critical intersections as compared to total number is high which makes wedge sliding is a greater concern for this slope orientation. Footwall benches were found to be favorable for wedge failures. Wedges were formed by the intersection of discontinuities $50^o/170^o$ and $50^o/220^o$. The analysis shows that the wedge stability or instability was mainly controlled by the properties of the schistocity plane.

Due to tendency of slope failures in footwall it is proposed to monitor it with various instruments in footwall side in addition to monitoring with total station. Joints are also observed to be favorable for instability in footwall side compared to hangwall. Joint sets of hangwall (Joints set no., dip/dip direction) are shown in the table 4.5.1 for kinematic analysis by using DIPS software.

4.5 Joint Survey Analysis for Hangwall (Strike/ Dip) [13]

Table 4.5.1: Joint sets of hangwall - Dongri-Buzurg mine

Location	Joint sets from hemispherical projection [Joint set no., dip (o) / dip direction (o)]
Hangwall	0. 50 / 175 (Schistocity) 1. 75 / 060 2. 43 / 325 3. 55 / 135

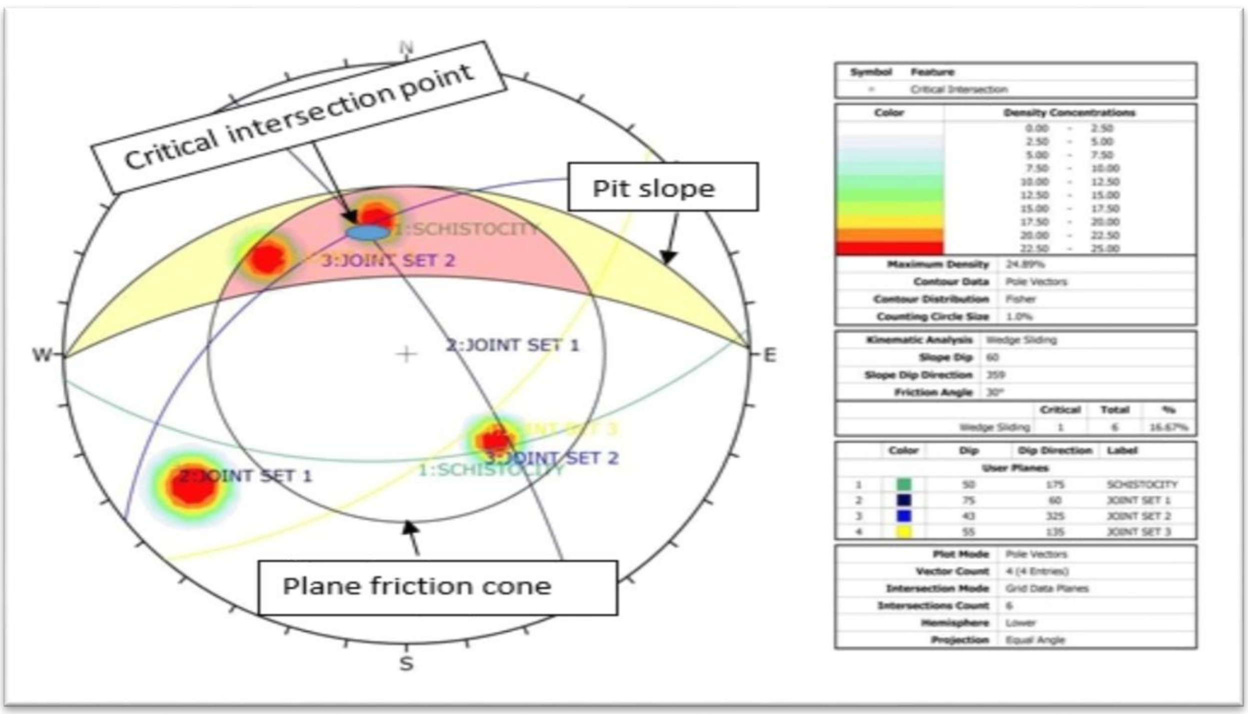


Fig. 4.5: Kinematic check for hangwall benches – MOIL Dongri Buzurg

Legend from Hangwall wedge sliding (DIPS)

A summary of wedge sliding result is displayed in legend (Table 4.5.2)

Table 4.5.2: Legend from footwall wedge sliding

Kinematic analysis	Wedge sliding		
Slope dip	60^0		
Slope dip direction	359^0		
Friction angle	30		
	Critical	**Total**	**Percentage**
Wedge sliding	1	6	16.67 %

In the fig. 4.5.1, there are four mean set planes intersect each other to form six intersection points. Among all six intersection points there is only one intersection point which is lying in the critical wedge sliding zone. Hence percentage of critical point is very less i.e. 16.67 %.

The hangwall strata also contain three sets of joints: one $75^0/060^0$ (planar, smooth surfaces); the second one $43^0/325^0$ (planar, rough surfaces); and the third set $55^0/135^0$ (rough, irregular). In addition, the schistocity has a prominent trend of $50^0/175^0$. Hangwall benches were potential for small wedge failures wherever the joints $75^o/060^o$ and $43^o/325^o$ were prominent. The analysis results showed that the discontinuity plane $43^o/325^o$ was mainly controlling the stability or instability of the wedge. For wedge failures, three-dimensional analysis is performed. For a wedge to be kinematically free, two planes should intersect and the dip line of intersection must be less than the slope angle and its direction within +/ - 20^o that of slope face direction.

CHAPTER-5

LABORATORY TESTING

5. LABORATORY TEST OF COLLECTED SAMPLES

Core samples are taken of 4 nos. boreholes namely MDB17, MDB21, MDB22, and MDB29 (Table.5.1). Nomenclature for boreholes core samples are given in the manner. For Example: 17-1-1 represents as 17(borehole No), 1 denotes bench number and 1 denotes sample number. Photographs of some of the core samples are presented in fig 5.1 and fig.5.2.

Table 5.1: Core samples of Dongri Buzurg Mine

Bore Hole Number:- MDB17, MRL 378.50, CH-45, Drilled-90^0				
Sl. No.	**MRL**		**Sample Number**	**Rock Type**
	From	**To**		
1	346	336	17-1-1, 17-1-2, 17-1-3	Tirodi Biotite Gneiss
2	336	326	17-2-1, 17-2-2, 17-2-3	Quartzite muscovite schist
3	326	255	17-3-1, 17-3-2, 17-3-3	Quartzite muscovite schist with Rhodonite
4	255	242	17-4-1, 17-4-2,	Mn ore Rhodonite
Bore Hole Number:- MDB21, MRL 345, CH-35, Drilled-85^0 due North				
1	328	319	21-1-1, 21-1-2, 21-1-3	Tirodi Biotite Gneiss
2	319	309	21-2-1, 21-2-2, 21-2-3	Tirodi Biotite Gneiss

3	309	299	21-3-1, 21-3-2, 21-3-3	Tirodi Biotite Gneiss
4	299	290	21-4-1, 21-4-2, 21-4-3	Tirodi Biotite Gneiss
5	290	279	21-5-1, 21-5-2, 21-5-3	Tirodi Biotite Gneiss
6	279	269	21-6-1, 21-6-2, 21-6-3	Tirodi Biotite Gneiss, last one is Quartz muscovite schist
7	269	259	21-7-1, 21-7-2, 21-7-3	Quartz muscovite schist
8	259	249	21-8-1, 21-8-2, 21-8-3	Quartz muscovite schist
Bore Hole Number:- MDB22, MRL 350, CH-24, Drilled-85^{0} due North				
1	326	312	22-1-1, 22-1-2, 22-1-3	Granitic gneiss
2	312	298	22-2-1, 22-2-2, 22-2-3	Granitic gneiss
3	298	287	22-3-1, 22-3-2, 22-3-3	Quartz muscovite schist
4	287	277	22-4-1, 22-4-2, 22-4-3	Quartz muscovite schist

5	277	265	22-5-1, 22-5-2, 22-5-3	Quartz muscovite schist
Bore Hole Number:- MDB29, MRL 346, CH-41, Drilled-85^0 due North				
1	338	332	29-1-1, 29-1-2, 29-1-3	Tirodi Biotite Gneiss
2	332	319	29-2-1, 29-2-2, 29-2-3	Tirodi Biotite Gneiss
3	319	309	29-3-1, 29-3-2, 29-3-3	Tirodi Biotite Gneiss
4	309 and below		29-4-1, 29-4-2, 29-4-3	Quartz mica schist
5	150 MRL		29-5-1, 29-5-2, 29-5-3	Mn ore

Some of the photo graphs taken whiling collecting raw sample at Dongri Buzurg mine are shown in fig. 5(a) and fig. 5(b).

Fig.5 (a): Bore hole samples of Dongri Buzurg Mine

Fig.5 (b): Bore hole samples of Dongri Buzurg Mine

5.1 Testing of Samples

The samples were collected from Dongri Buzurg (MOIL) mine footwall are tested in the laboratory to determine the physico-mechanical properties. Strength properties of rock mass were determined using RMR and uniaxial compressive strength of intact rock. Shear strength properties of intact rock samples were determined in Triaxial testing. Different phases of sample preparation are shown in fig. 5.1.1.

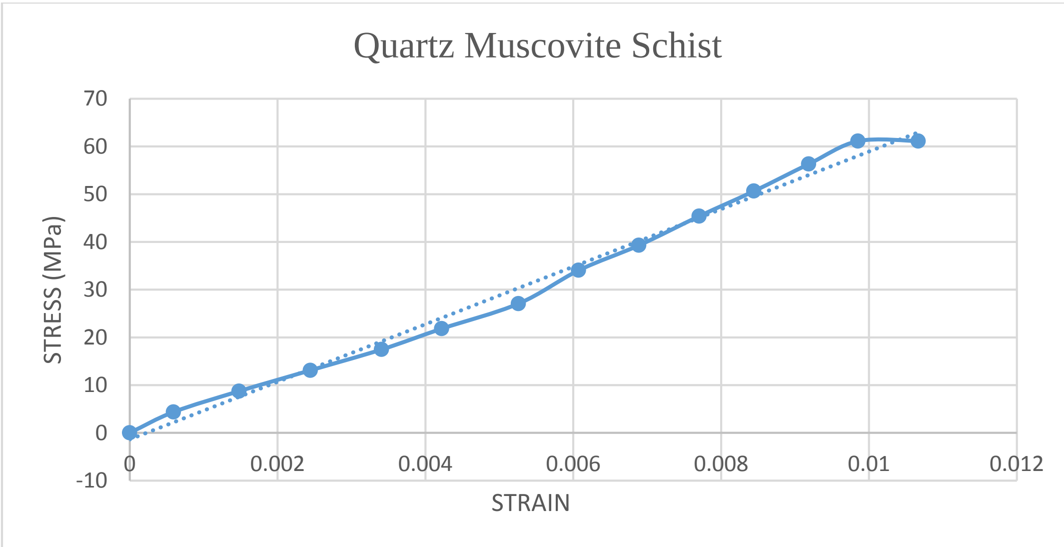
Fig.5.1.1: Sample Preparation

5.1.1 Uniaxial testing profile & graphical representation of properties

As rock samples were prepared for different testing in the laboratory for determining the physico-mechanical properties by Uniaxial compressive strength test for knowing the value of young modulus and their compressive strength. So for that different rock after UCS testing are shown with their fracture profile in the fig. 5.1.1 (a) to fig.5.1.1(c).

(a) Quartz Muscovite Schist

Fig.5.1.1 (a). Fracture profile of Quartz Muscovite Schist after completion of UCS test.



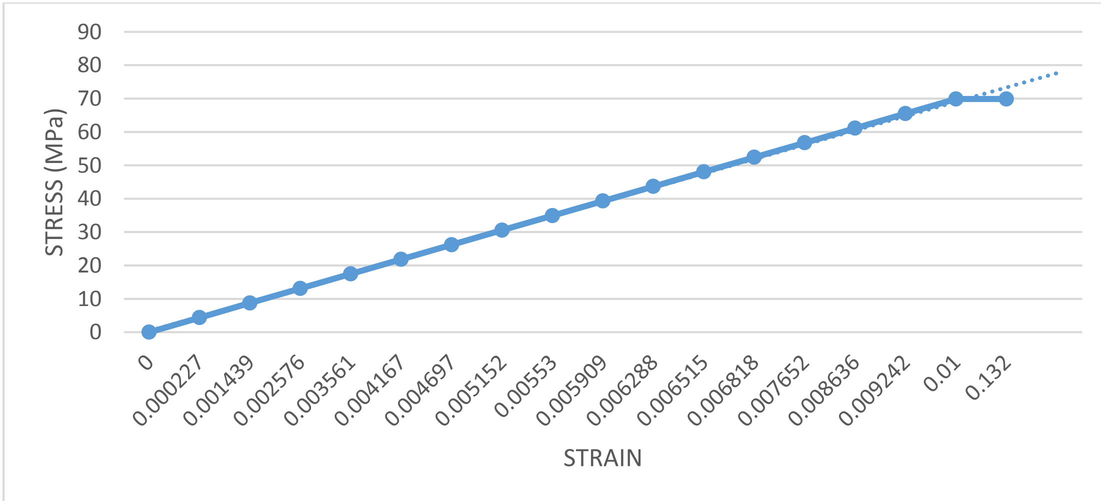
Graph 5.1.1(a): Stress vs. Strain graph for Quartz Muscovite Schist sample

From above graph 5.1.1(a), UCS has been calculated i.e. (stress/strain)

UCS = 55 MPa & Young's modulus =2.5 GPa

(b) Tirodi Biotite Gneiss

Fig.5.1.1 (b). Fracture profile of Tirodi Biotite Gneiss after completion of UCS test.



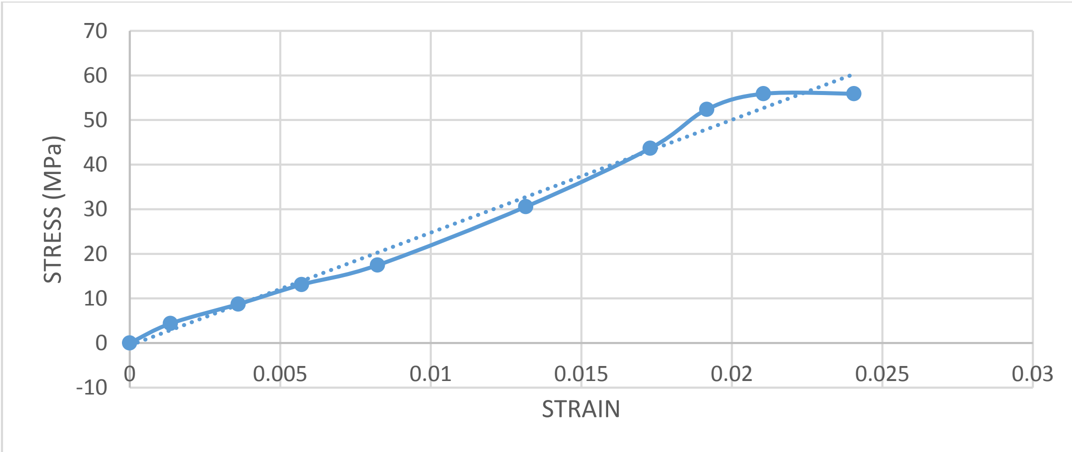
Graph 5.1.1(b): Stress vs. Strain graph for Tirodi Biotite Gneiss sample.

From above graph 5.1.1(b), UCS has been calculated i.e. (stress/strain)

UCS = 69.86 MPa & Young's modulus =6.9 GPa

(c) Quartz Mica Schist

Fig.5.1.1(c): Fracture profile of Quartz Mica Schist after UCS test.



Graph 5.1.1(c): Stress vs. Strain graph for Quartz mica schist sample.

From above graph 5.1.1(c), UCS has been calculated i.e. (stress/strain)

UCS = 61.12 MPa & Young modulus =6.11 GPa

5.1.2 Triaxial testing, profile & Mohr's circle representation

Triaxial testing was done to know their cohesion and angle of internal friction. There fracture profile after Triaxial testing are shown in figure 5.1.2(a) to fig. 5.1.2(b).

(a) Tirodi Biotite Gneiss

Fig.5.1.2 (a). Fracture profile of Tirodi Biotite Gneiss after Triaxial test.

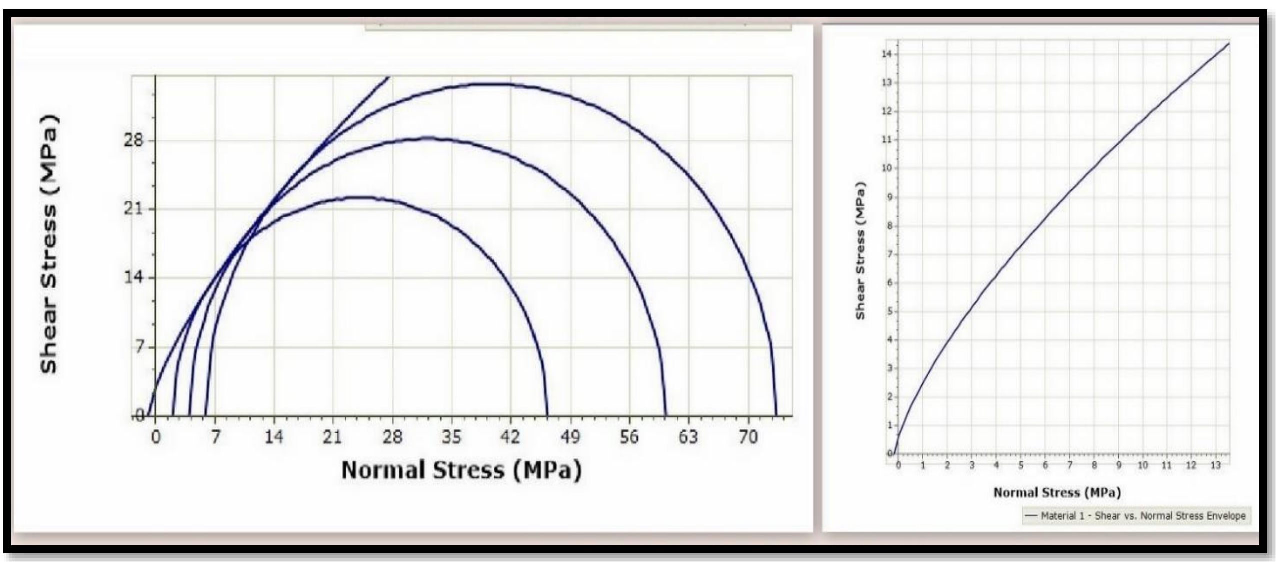
Data Point: Failure criterion:

Using the "RocData" software for representing Mohr's circle [graph 5.1.2(a)] for Tirodi Biotitic gneiss gives the following information about their physico-mechanical properties i.e.

Cohesion = 2.13 MPa

Friction angle = 39.6^0

σ_3 (MPa	**σ_1 (MPa)**
1.96	**46.28**
3.92	**60.26**
5.89	**73.36**



Graph 5.1.2(a): Mohr circle and shear vs. normal stress curve for Tirodi Biotite Gneiss sample

(b) Granitic Gneiss

Fig.5.1.2 (b): Fracture profile (top view & side view) of Granitic Gneiss sample after Triaxial Test.

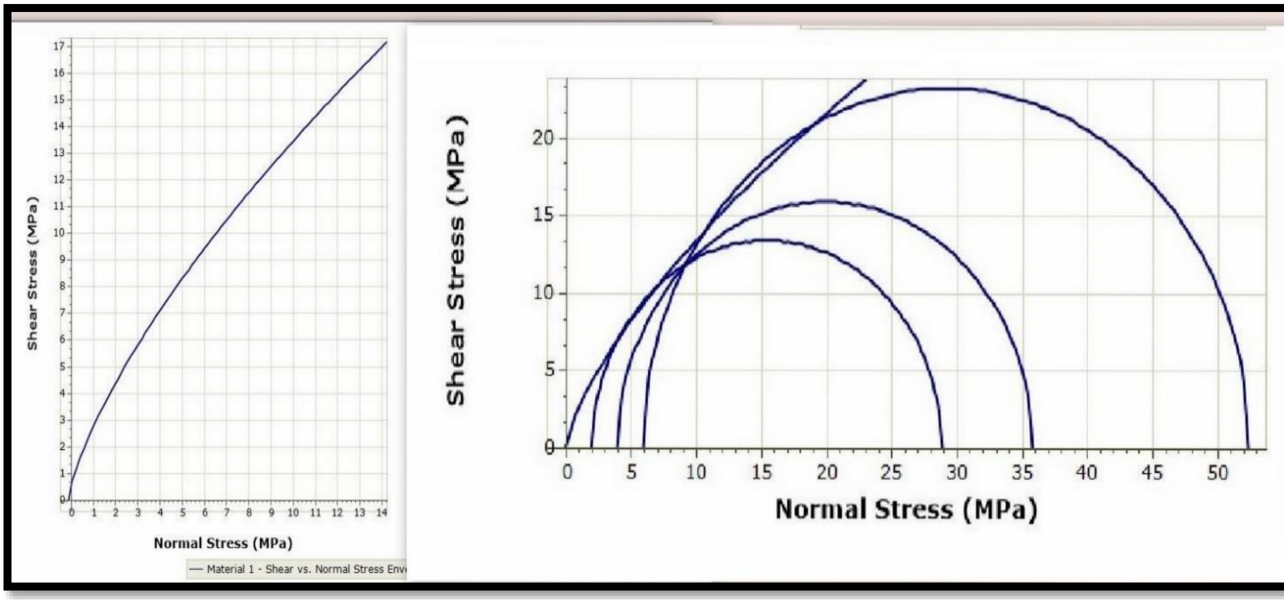
Data Point: Failure criterion:

Using the “RocData” software for representing Mohr’s circle [graph 5.1.2(b)] for Granitic gneiss gives the following information about their physico-mechanical properties i.e.

Cohesion = 2.4 MPa

Friction angle = 41.9^0

σ_3 (MPa	**σ_1 (MPa)**
1.96	**28.82**
3.92	**35.8**
5.89	**52.39**



Graph 5.1.2(b): Mohr circle and shear vs. normal stress curve for Granitic Gneiss sample

(c) Quartz mica schist

Fig.5.1.2(c): Fracture profile (side view & top view) of Quartz Mica Schist sample.

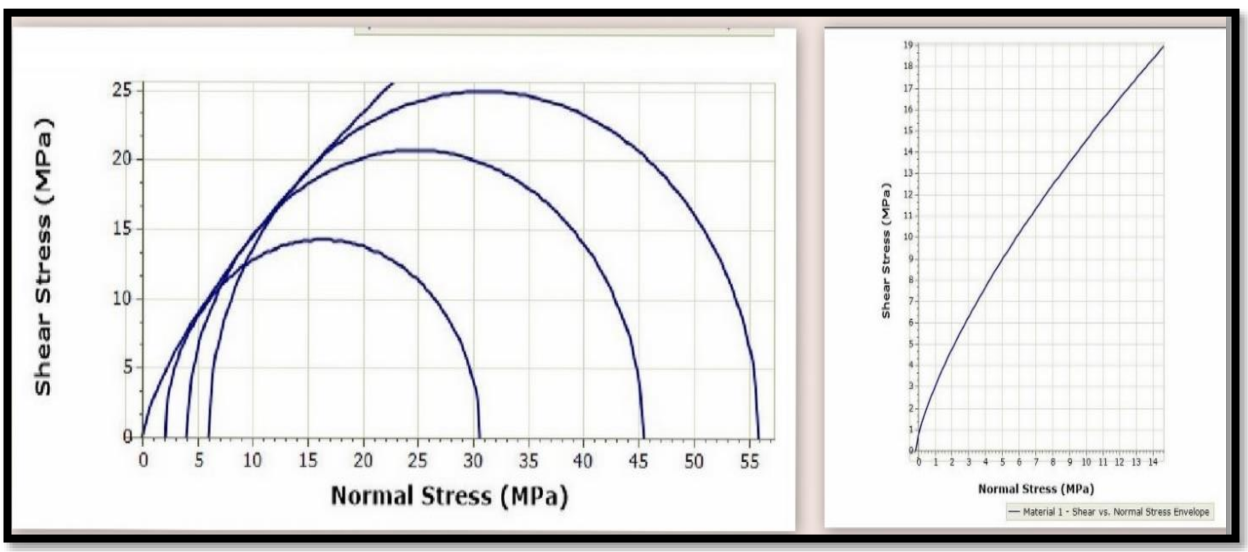
Data Point: Failure criterion:

Using the "RocData" software for representing Mohr's [graph 5.1.2(c)] circle for Granitic gneiss gives the following information about their physico-mechanical properties i.e.

Cohesion = 2.64 MPa

Friction angle = 43.9^0

σ_3 (MPa	σ_1 (MPa)
1.96	**60.56**
3.92	**45.41**
5.89	**55.89**



Graph 5.1.2(c): Mohr circle and shear vs. normal stress curve for Quartz Mica Schist sample

From above experimental analysis of the physico-mechanical properties i.e. UCS, RQD, spacing of discontinuities, condition of discontinuities & ground water condition, of different rock and & joint survey of the MOIL-Dongri Buzurg mine summed up to give the basic RMR by Bieniawski's geomechanics classification.

5.2 Summary of Physico-Mechanical Properties of Rock- Dongri Buzurg MOIL

Summary of different laboratory tested results are summarized in the table 5.2.1 and 5.2.2.

Table 5.2.1: Summary of Bulk density, UCS and Young Modulus values from laboratory Testing

ROCK TYPE	BULK DENSITY (Kg/m^3)	UCS (MPa)	YOUNG'S MODULUS (GPa)
Quartz muscovite schist	2872	55	2.5
Tirodi biotitic gneiss	2701	69.86	6.9
Quartz mica schist	2859	61.12	6.11
Mica schist [13]	2766	22.06	7.91

Table 5.2.2: Summary of Bulk density, Cohesion and friction angle from laboratory Triaxial Testing

	Bulk density	Cohesion (MPa)	Friction angle
Tirodi biotitic gneiss	**2701**	**2.13**	**39.6^0**
Granitic gneiss	**2830**	**2.4**	**41.9^0**
Quartz mica schist	**2859**	**2.64**	**43.9^0**
Mica schist [13]	**2766**	**1.56**	**27.5^0**

5.3 ROCK MASS CLASSIFICATION

Bieniawski's geomehanics classification, also known as rock mass rating (RMR) was initially developed for tunnel in South Africa but later it was widely used in mines with some modification. RMR for Dongri Buzurg mine, as per above calculated values are shown in table 5.3.1

Table 5.3.1: RMR Classification parameters & ratings for MOIL-Dongri Buzurg

Sl. No.	Parameter	Range of values					**MOIL**
1	Spacing of joints (cm)	< 6	6 - 20	20 -60	60-200	>200	**16**
	Rating	0-5	6-8	9-10	11-15	16-20	
2	Condition of joints	Slickensides soft gouge continuous	Slickensides 1-5 mm gouge continuous	Slightly rough < 1 mm soft gouge	Rough, fresh discontinuous	V. rough , tight , fresh discontinuous	**3**
	Rating	0-4	5-10	11-20	21-25	26-30	
3	RQD (%)	< 25	25-50	50-75	75-90	>90	**3**
	Rating	0-3	4-8	9-13	14-17	18-20	
4	Rock strength (kg/cm^2)	<250	250-500	500-1000	1000-2500	>2500	**6**
	Rating	0-2	3-4	5-7	8-12	13-15	

5	Ground water (l/min)	>125	25-125	>25	Wet	Dry	**14**
	Rating	0	1-4	5-7	8-10	11-15	
Total							**42**

Depending on the RMR, the rock mass can be classified as given in the following table 5.3.2

Table 5.3.2. Category of rock on the basis of RMR

RMR	**ROCK DESCRIPTION**
0-20	Very Poor
20-40	Poor
40-60	Fair
60-80	Good
80-100	Very Good

Calculated value of RMR of the MOIL-Dongri Buzurg is 42 which is coming under FAIR category of rock type according to above table 5.3.2.

CHAPTER-6

PARAMETRIC STUDIES

6. BRIEFING ABOUT BENCH PARAMETER USED FOR NUMERICAL MODELLING

To study the effect of pit slope angle on factor of safety, parametric study was done by using FLAC slope & OASYS software for footwall bench. Similarly for hangwall, only FLAC slope software was used. The effect of pit slope angle on safety factor are summarized in table 6.1 and table 6.2. These parametric studies were done on rock mass properties of Dongri Buzurg mines-MOIL, which was calculated in laboratory testing. Different bench parameter considered during analysis are: Bench height- 10 m, Bench width – 15 m. Other rock mass properties were summarized in table 5.2.1 and table 5.2.2. Now in section 6.1, comparative study for stability of footwall at different bench angle by using FLAC & OASYS are being done. Here use of OASYS software is only for analyzing the trend of their factor of safety with their input of bench angle. Prominently consideration for the factor of safety is only of FLAC software for field implementation.

6.1 Comparative Study For Stability Analysis of Footwall at Different Bench Angle by Using FLAC & OASYS:

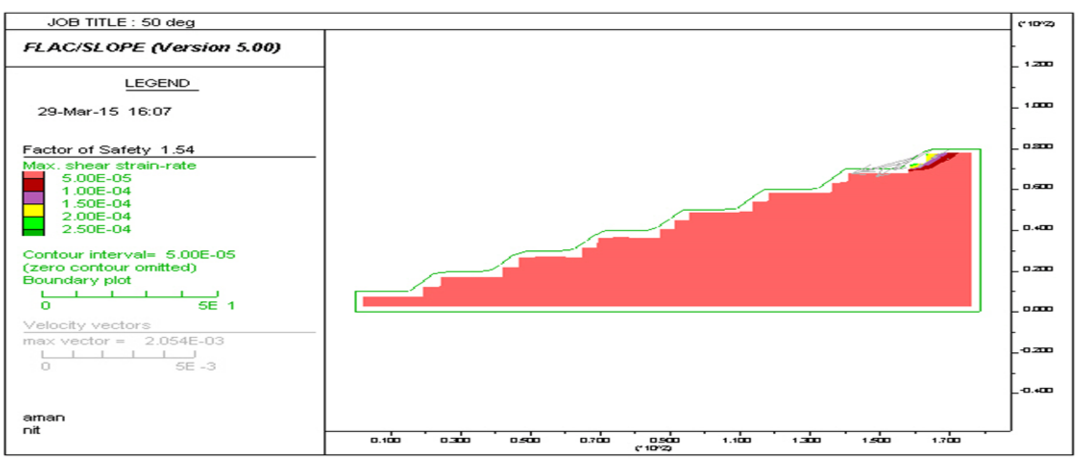


Fig.6.1 (a) Stability analysis of footwall at 50^0 bench slope with safety factor 1.54 by FLAC

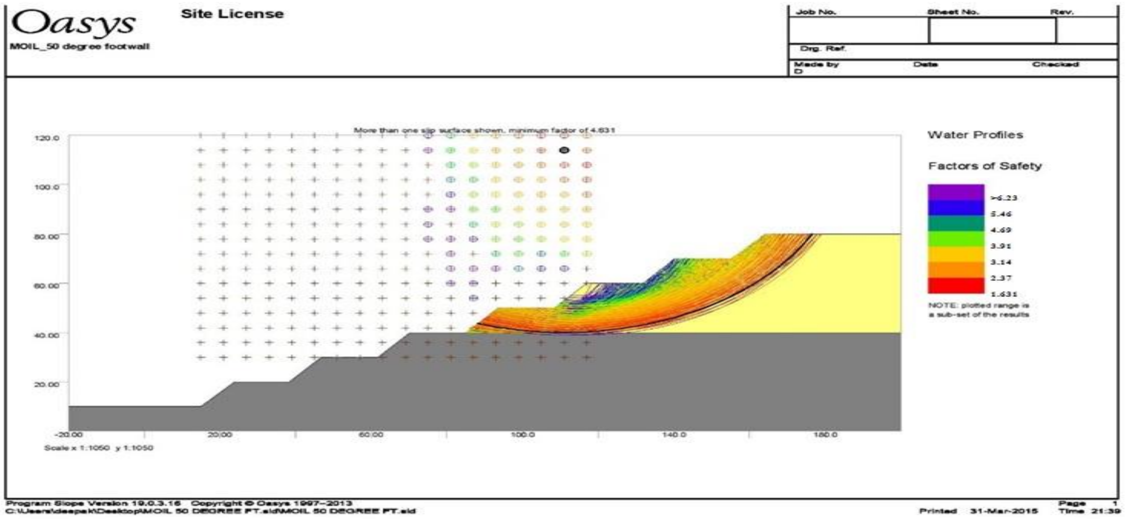


Fig.6.1 (b) Stability analysis of footwall at 50^0 bench slope with safety factor 1.63 by OASYS

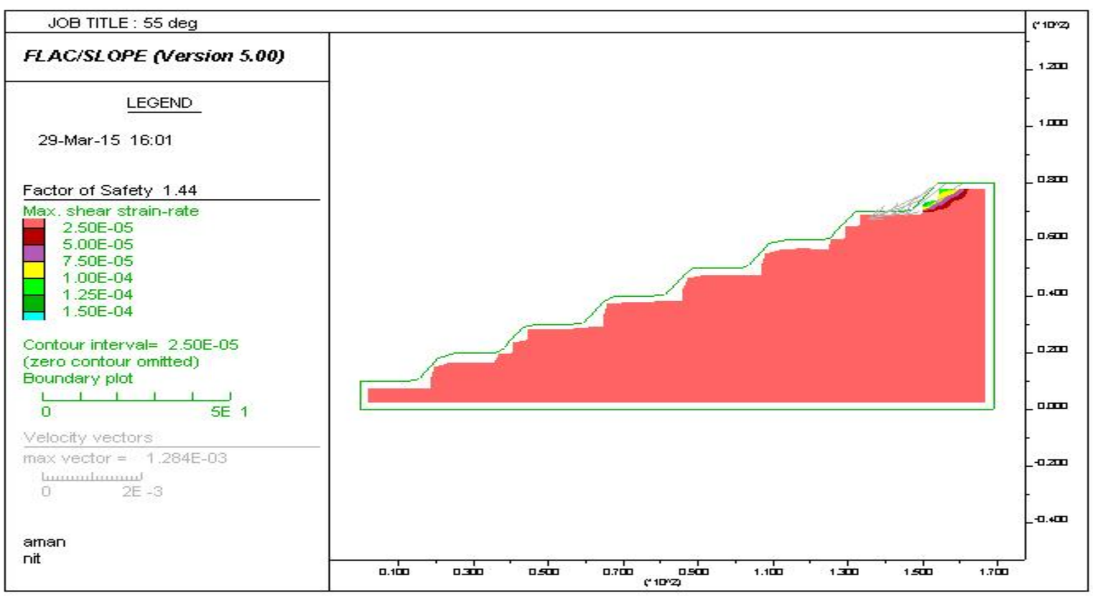


Fig.6.1 (c) Stability analysis of footwall at 55^0 bench slope with safety factor 1.44 by FLAC

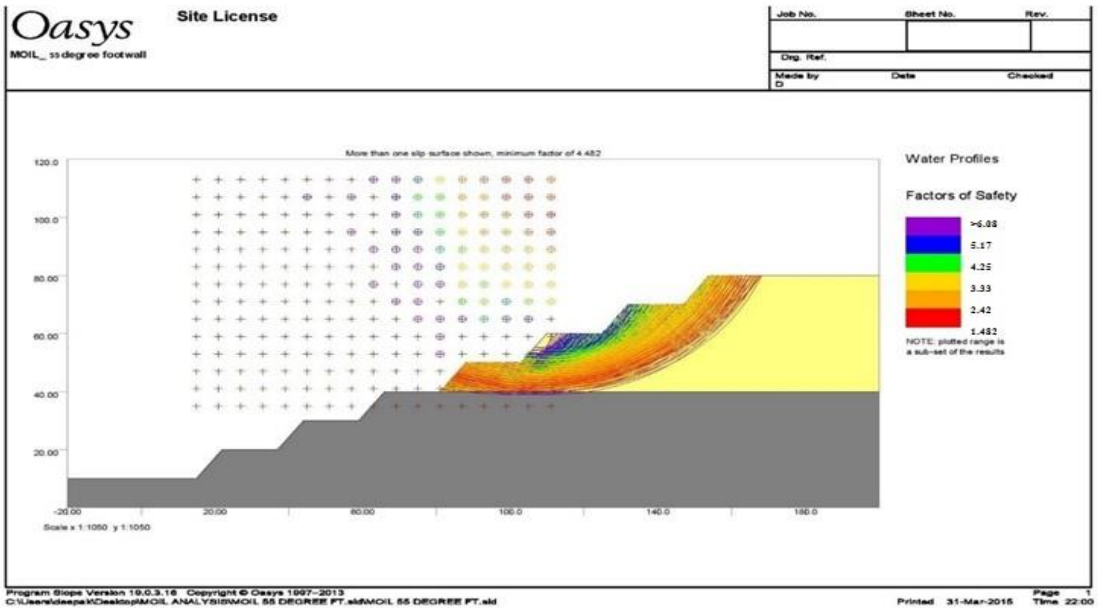


Fig.6.1 (d) Stability analysis of footwall at 55^0 bench slope with safety factor 1.48 by OASYS

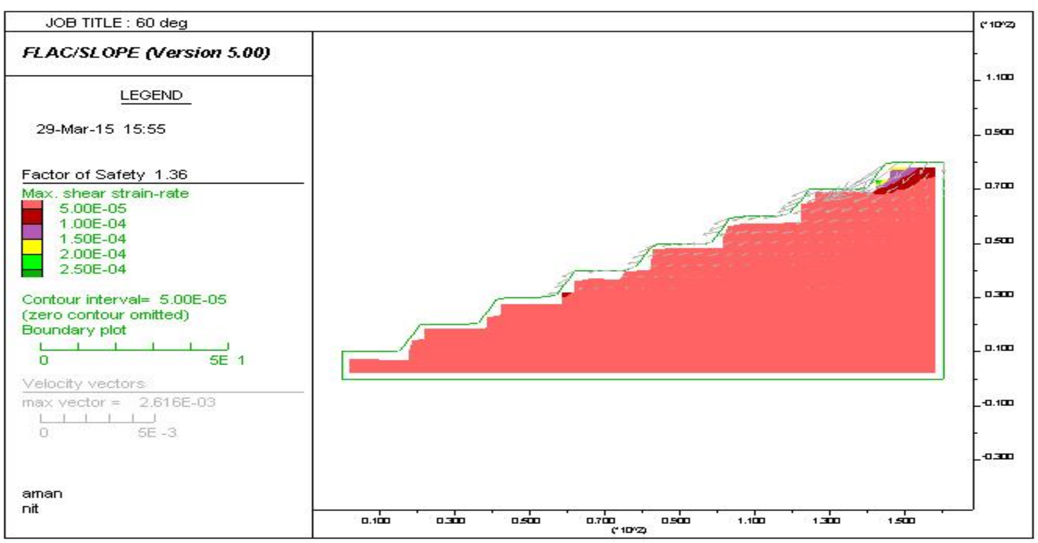


Fig.6.1 (e) Stability analysis of footwall at 60^0 bench slope with safety factor 1.38 by FLAC

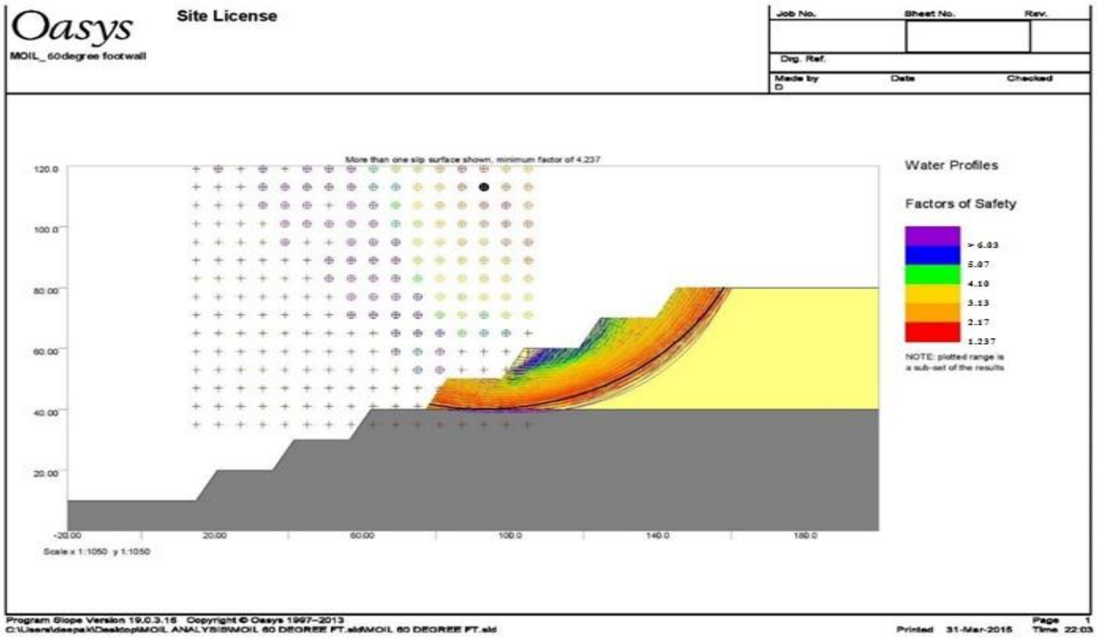


Fig.6.1 (f) Stability analysis of footwall at 60^0 bench slope with safety factor 1.237 by OASYS

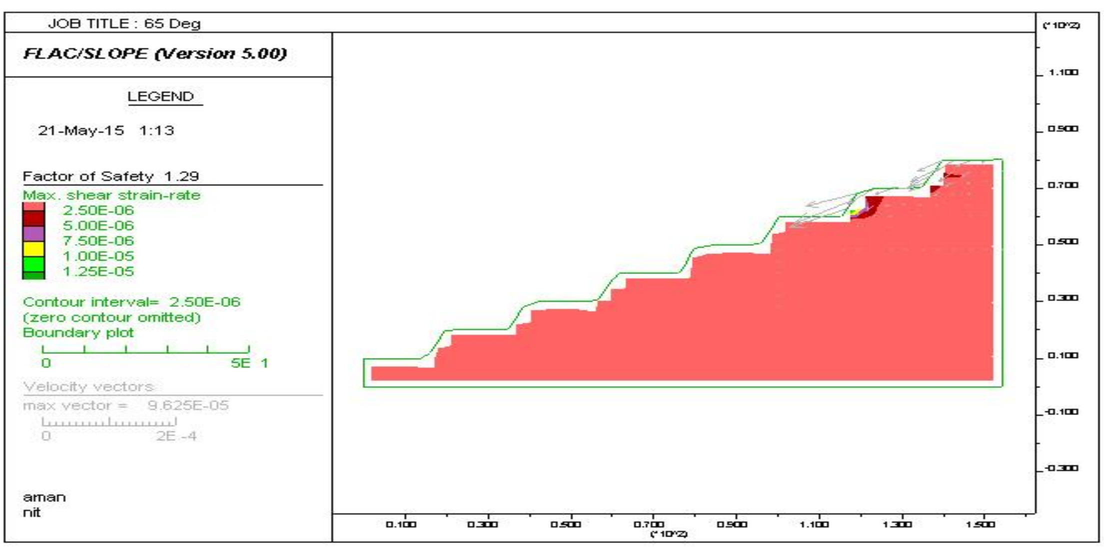


Fig.6.1 (g) Stability analysis of footwall at 65^0 bench slope with safety factor 1.29 by FLAC

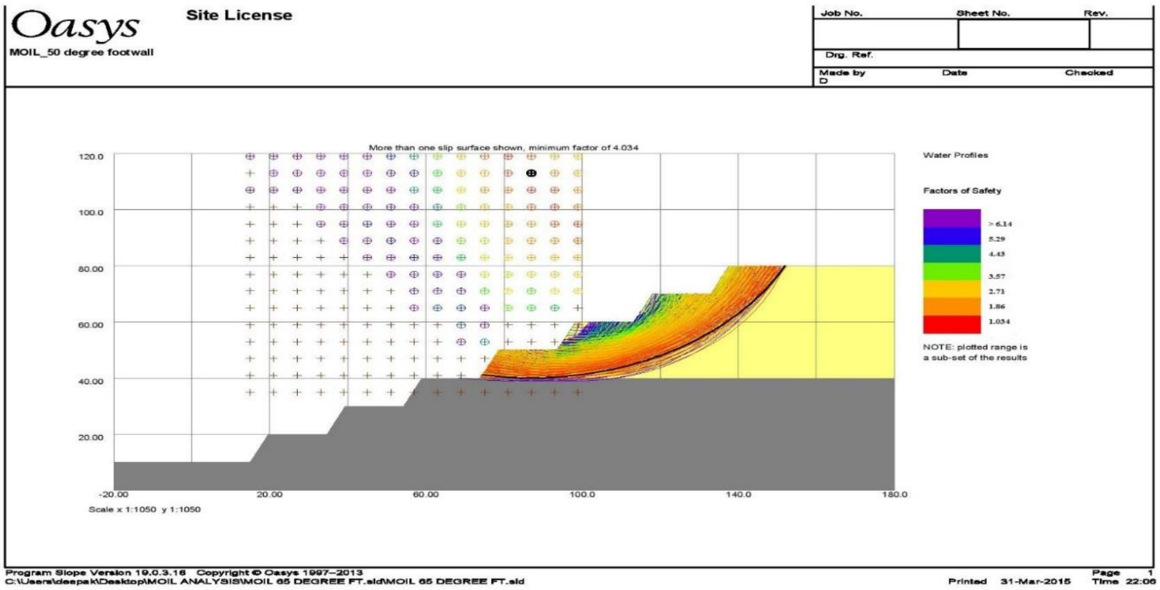


Fig.6.1 (h) Stability analysis of footwall at 65^0 bench slope with safety factor 1.034 by OASYS

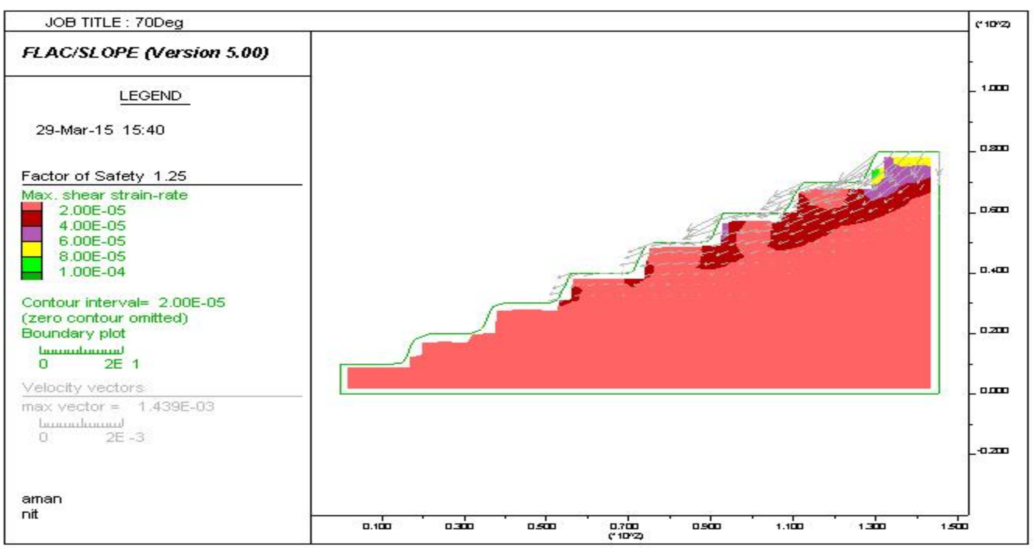


Fig.6.1 (i) Stability analysis of footwall at 70^0 bench slope with safety factor 1.25 by FLAC

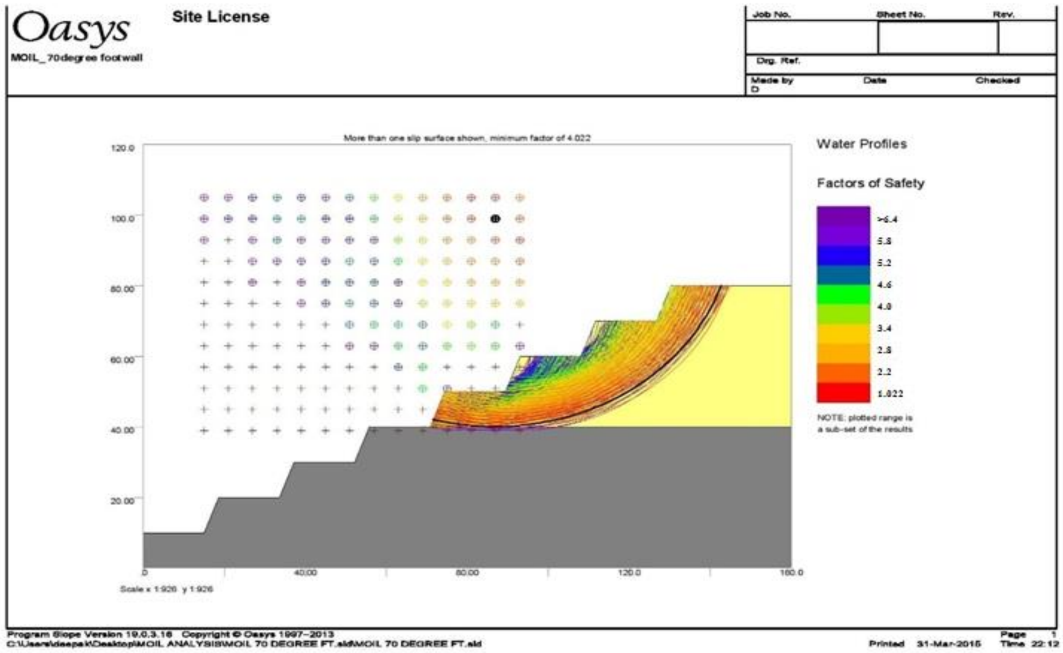


Fig.6.1 (j) Stability analysis of footwall at 70^0 bench slope with safety factor 1.022 by OASYS

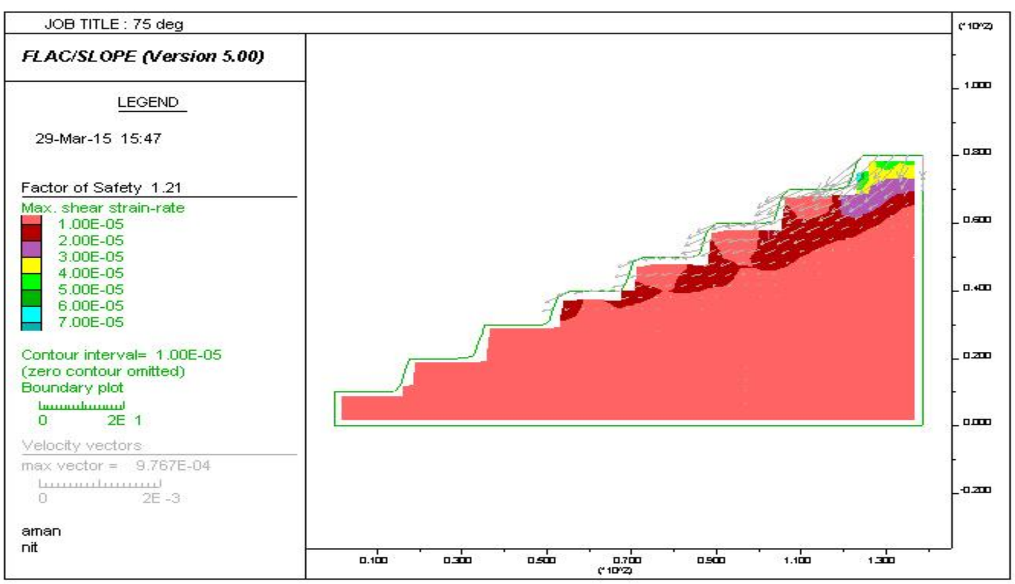


Fig.6.1 (k) Stability analysis of footwall at 75^0 bench slope with safety factor 1.21 by FLAC

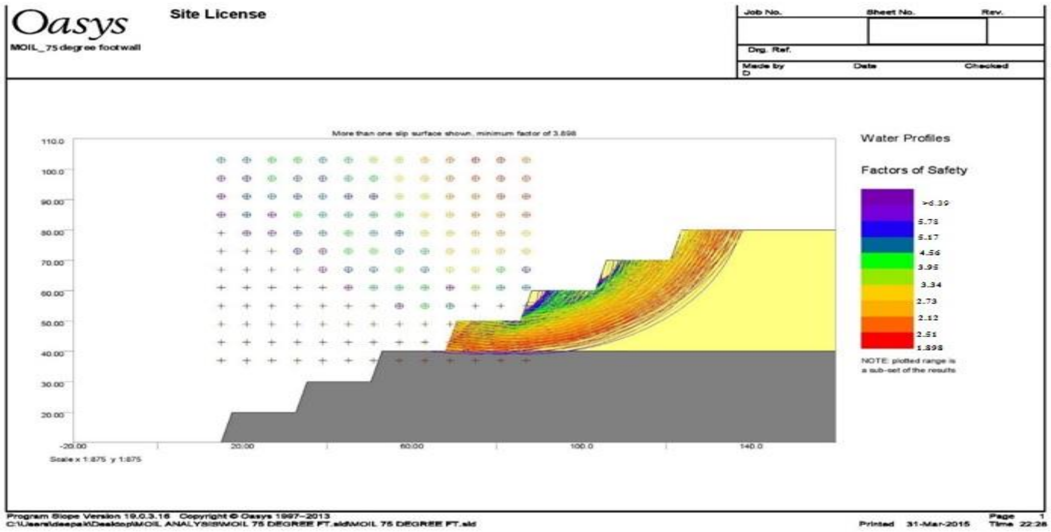


Fig.6.1 (l) Stability analysis of footwall at 75^0 bench slope with safety factor 0.898 by OASYS

From above analysis of the FLAC & OASYS modelling from fig.6.1 (a) to fig.6.1 (j), we found out the following result w.r.t factor of safety at different bench angle of footwall as shown in table 6.1.

Table 6.1 Factor of safety of footwall with variation of bench angle using FLAC & OASYS

Bench angle of footwall	Factor of safety by FLAC	Factor of safety by OASYS
50^0	1.54	1.63
55^0	1.44	1.48
60^0	1.36	1.23
65^0	1.29	1.034
70^0	1.25	1.02
75^0	1.21	0.89

6.2 Stability Analysis of Hangwall at Different Bench Angle by Using FLAC

Parametric study for hangwall is not a big concern as compared to footwall, as it is surrounded with hard rock which can bear high stress and driving forces. Different bench angle for hangwall with bench height 10 m and bench width 15m are analyzed with FLAC and shown below in fig. 6.2(a) to fig. 6.2(i).

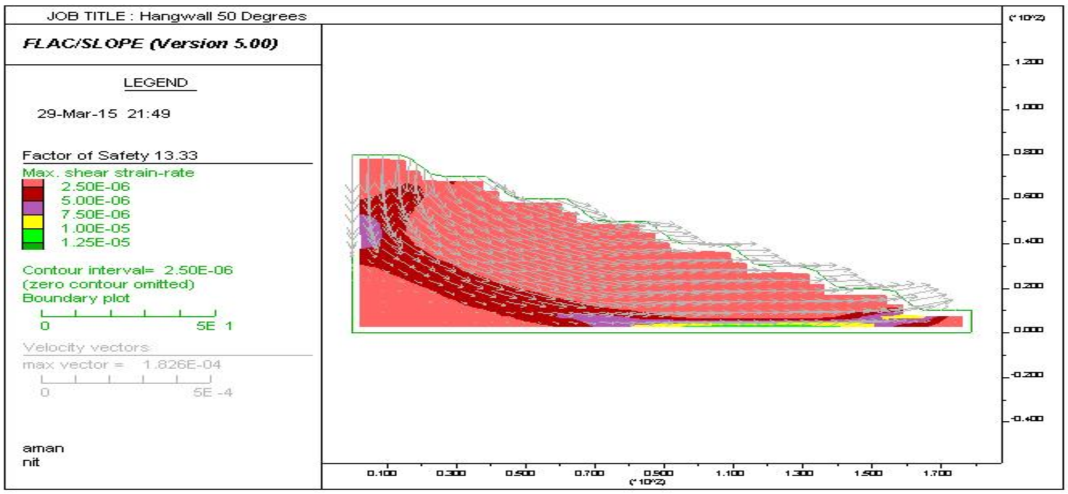


Fig.6.2 (a) Stability analysis of hangwall at 50^0 bench slope with safety factor 13.33

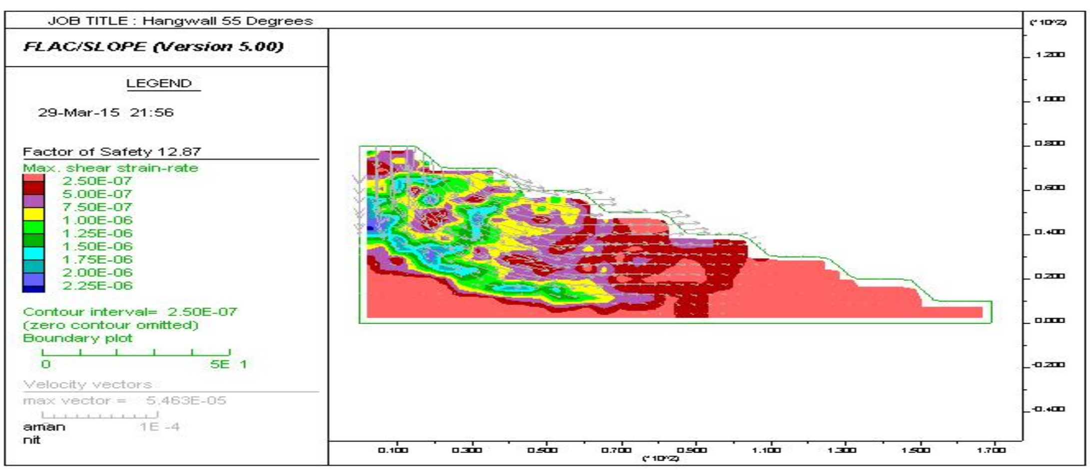


Fig.6.2 (b) Stability analysis of hangwall at 55^0 bench slope with safety factor 12.87

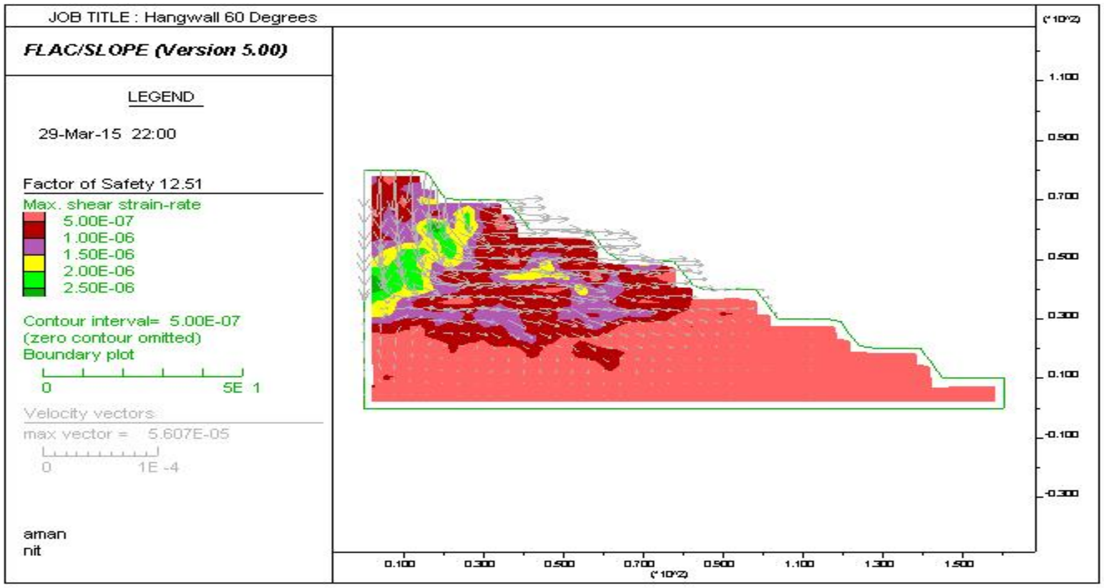


Fig.6.2 (c) Stability analysis of hangwall at 60^0 bench slope with safety factor 12.51

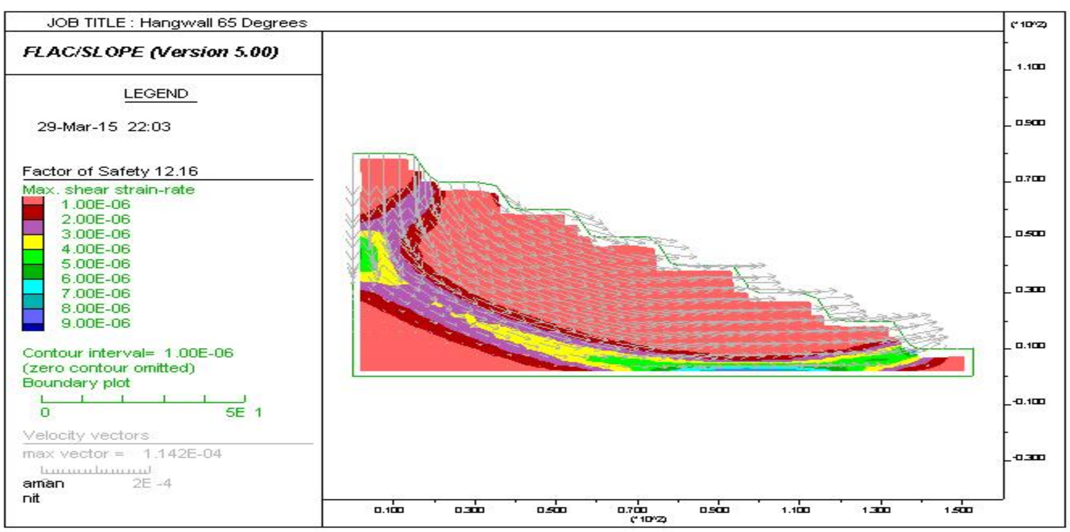


Fig.6.2 (d) Stability analysis of hangwall at 65^0 bench slope with safety factor 12.16

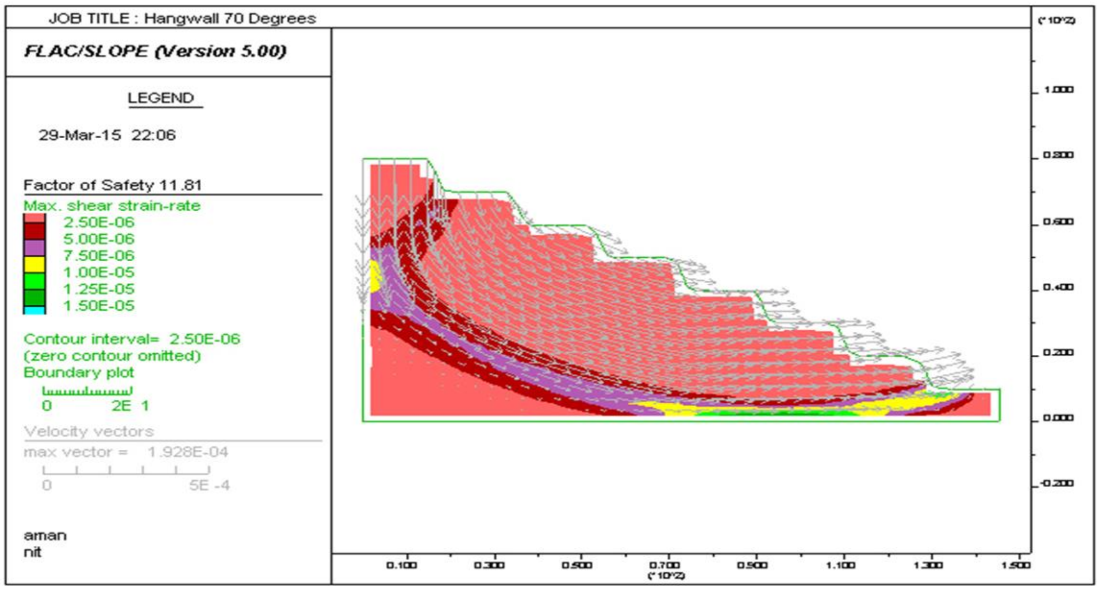


Fig.6.2 (e) Stability analysis of hangwall at 70^0 bench slope with safety factor 11.81

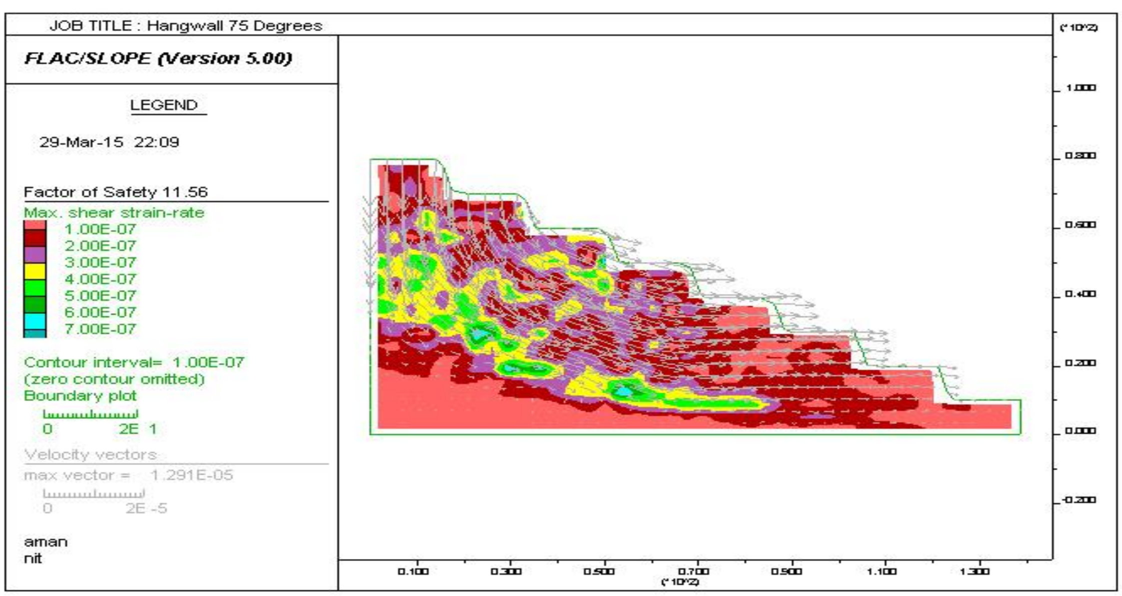


Fig.6.2 (f) Stability analysis of hangwall at 75^0 bench slope with safety factor 11.58

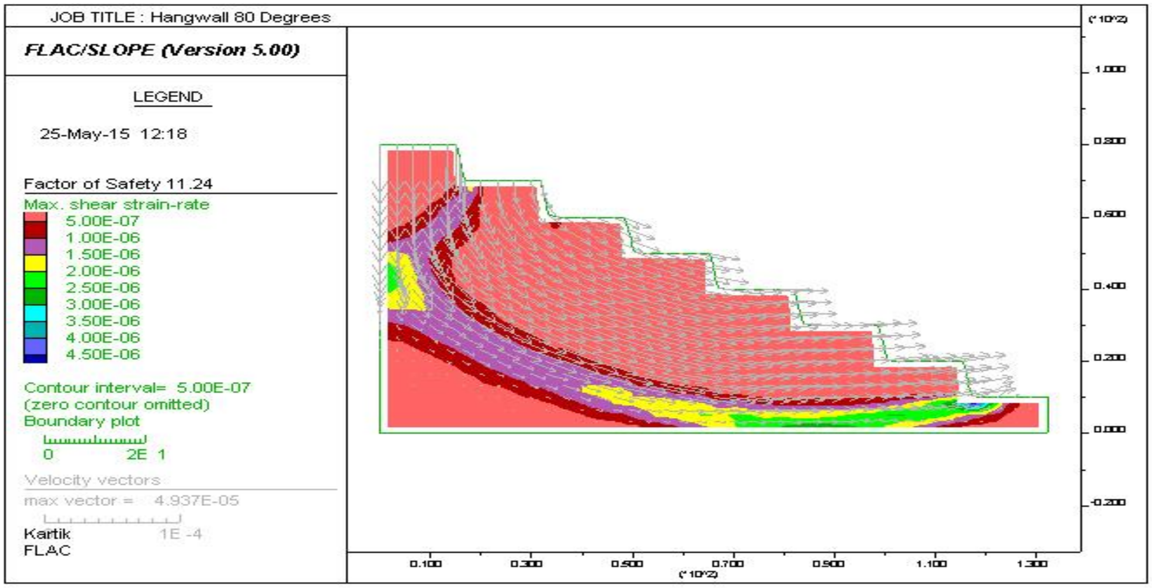


Fig.6.2 (g) Stability analysis of hangwall at 80^0 bench slope with safety factor 11.24

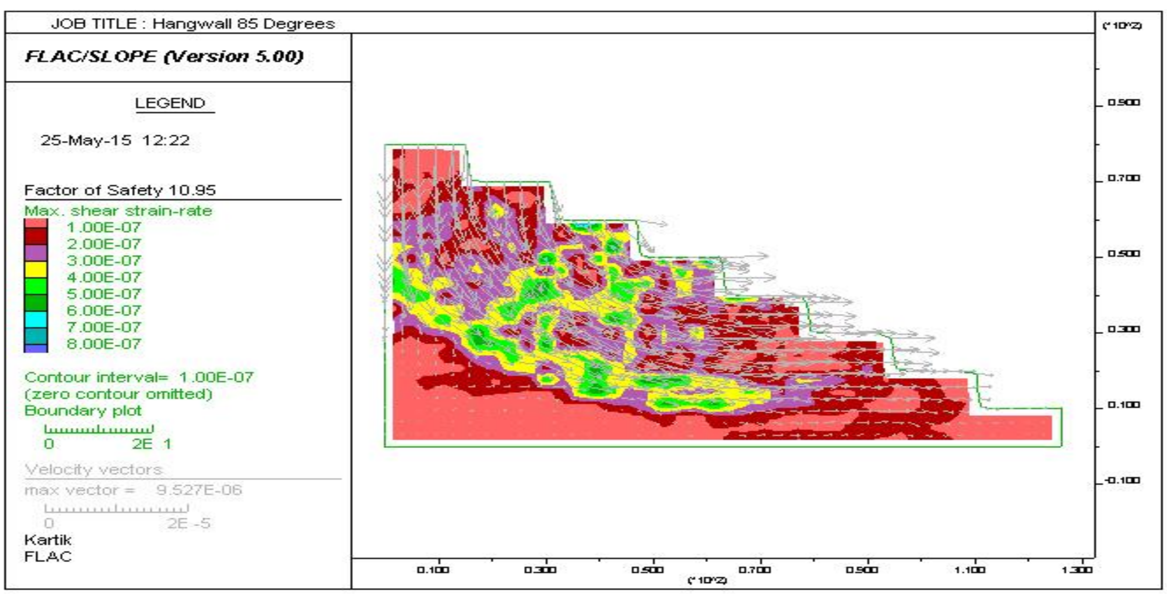


Fig.6.2 (h) Stability analysis of hangwall at 85^0 bench slope with safety factor 10.95

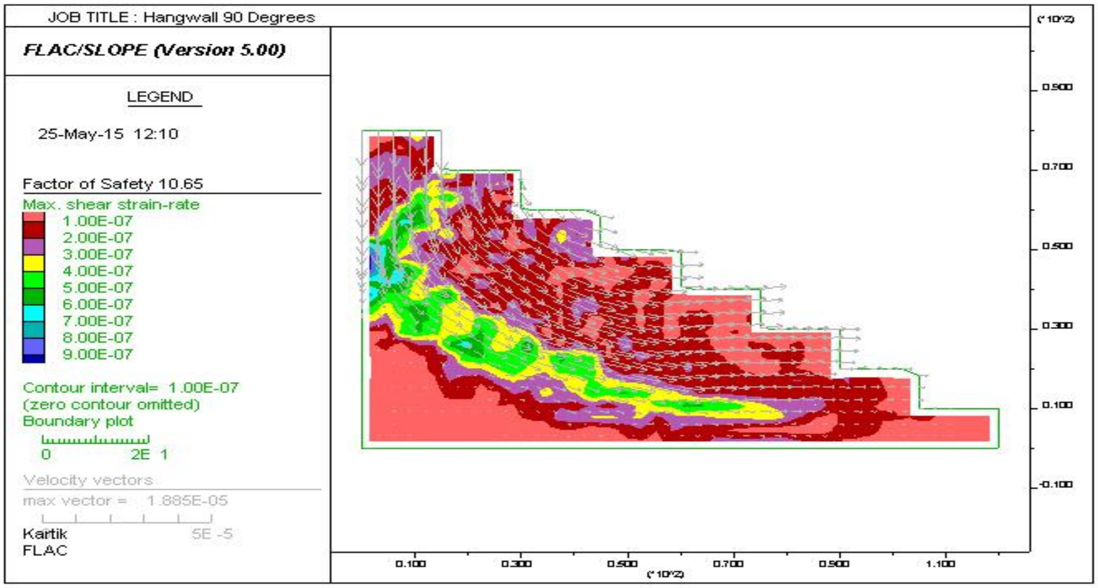


Fig.6.2 (i) Stability analysis of hangwall at 90^0 bench slope with safety factor 10.65

From above analysis of the FLAC modelling, we found out the following result w.r.t factor of safety at different bench angle of hangwall as shown in table 6.2.

Table 6.2. Factor of safety of Hangwall with variation of bench angle using FLAC

Bench angle of Hangwall	Factor of safety
50^0	13.37
55^0	12.87
60^0	12.51
65^0	12.16
70^0	11.81
75^0	11.58
80	11.24
85	10.95
90	10.64

6.3 Result and Discussion

From above Numerical analysis, factor of safety for footwall decrease as the bench angle gradually increases is summarized in the table 6.1 by using two software i.e. FLAC slope and OASYS. The analysis of table 6.1 gives an idea about that up to a bench angle of 75^0 gives an safety factor of 1.21, which is just more than 1.2 and hence considered to be safe in the mine, but due to occurrence of possible error in calculation of rock properties during lab testing, human error, it could not be implemented in field. Now analyzing the bench angle of 70^0, factor of safety is now 1.25 which is quite good to be implemented in the field which would not pose high potential of any type of failure. But at the same time for bench angle of 65^0, the safety factor is 1.29 which is more than sufficient to be considered in the field and hence can be implemented.

Now as far as hangwall is concern, here also factor of safety decrease as bench angle gradually increases but amount of decrease in safety factor doesn't bother for any type of slope failure at hangwall side. Numerical analysis by using FLAC have much more factor of safety and have a value of more than 10.64 for bench angle of 90^0 even, as summarized in table 6.2 which is more than sufficient to satisfy factor of safety for hangwall of MOIL, Dongri Buzurg and there are no chances of failure for even 90^0 bench angle for hangwall according to numerical analysis by using FLAC. It doesn't bother anyway if we implement any slope angle for hangwall benches up to 90^0. As hangwall benches are mostly granitic gneiss which is hard rock and have capability to bear high driving force.

6.4 Limitation of Work

The following limitations have been identified for the approaches developed.

1. All the work done on slope stability would be on the basis of hard and soft rocks only, but not applicable for very soft rock or highly jointed rock mass.
2. Water level conditions near the mine was considered as unaffected (dry condition) by the slope stability up to any extent.
3. Slope stability was analyzed with fixed bench height and bench width. So this result would not be applicable for any other bench parameters.
4. Joint survey analysis was not considered while performing numerical modelling for slope stability analysis for footwall and hangwall using FLAC and OASYS software.

6.5 Recommendation for Further Work

As all the possible attempts and care were taken while performing joint survey, laboratory testing and analyzing the data by using software but it is not possible to implement all field situations. So for making it more practical it is required to go for more sample testing and analyzing the data by using three dimensional model for rock mass properties to get more authentic cut off point for stable and unstable slope angle with their various factor of safety.

CHAPTER-7

CONCLUSION

CONCLUSION

1. The joint survey at sites provided with the recognition of four sets of discontinuities including the schistocity at footwall strata with joint set no. and dip/dip direction magnitude are as 0. 50 / 170 (Schistocity), 1. 35 / 345, 2. 40 / 270, 3. 50 / 220 and hangwall 0. 50 / 175 (Schistocity), 1. 75 / 060, 2. 43 / 325, 3. 55 / 135.
2. Footwall benches were found to be favorable for wedge failures and Wedges were formed by the intersection of discontinuities $50^o/170^o$ and $50^o/220^o$. The analysis shows that the wedge stability or instability was mainly controlled by the properties of the schistocity plane. Hangwall benches have the potential for small wedge failures wherever the joints $75^o/60^o$ and $43^o/325^o$ were prominent.
3. Kinematic analysis of the joints by using DIPS software shows potential wedge failure in footwall side with 33.33% which shows sufficient potential failure in footwall side. And in hangwall side, it was 16.67% which has quite lower chances of failure.
4. Uniaxial compressive strength of Quartz muscovite schist, Tirodi biotitic gneiss and Quartz mica schist were determined as 55, 69.86 and 61.12 MPa respectively. Similarly, shear strength properties of rock were obtained by using Triaxial testing. Cohesion values were determined by using Triaxial tests values for Tirodi biotitic gneiss, Granitic gneiss and Quartz mica schist which were found to be 2.13, 2.4 & 2.64 MPa and have the friction angles measured as 39.6^0, 41.9^0, 43.9^0 respectively directly by using RocData software.
5. From parametric studies with above physico-mechanical properties, bench angle is determined to be 65^o with a bench height of 10 m for the geomining conditions of the MOIL-Dongri Buzurg mine.

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